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THESIS

STRUCTURAL ANALYSIS OF SLICE HULLS
by

Martin Rodriguez

March 1995

Thesis Advisor: **Charles N. Calvano**

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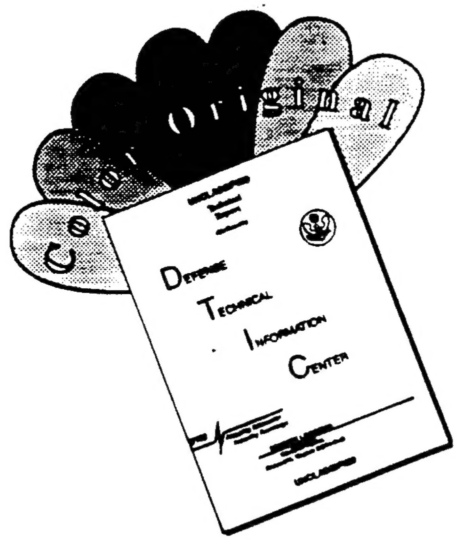

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STRUCTURAL ANALYSIS OF SLICE HULLS

by

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ABSTRACT

The overall objective of this work is to investigate the structural aspects of a novel hull design called SLICE, developed by Lockheed under contract to Office of Naval Research. The program MAESTRO (The Method for Analysis, Evaluation, and Structural Optimization), which is a finite element-PC based analysis tool designed to facilitate the modeling of ocean engineering structures was used for the investigation. A three dimensional model of the SLICE structure was exposed to six different load cases. Each load case represents a different wave to hull angle interaction. Three cases were subjected to sea state 5, and the last three cases were exposed to sea state 8. Since the SLICE lacks the continuous underwater hull that offers the large longitudinally rigidity for the SWATH, its longitudinal structure is of concern and the transverse structure becomes a concern with the possibility of severe torsional loads midships on the box. The following concerns are addressed in this work: 1. Compare and verify the SLICE structure's reactions to the different load cases with known SWATH reactions. 2. Verify if the beam seas which provide the maximum prying side force in the SWATH also affect the SLICE structure similarly. 3. Validate the program MAESTRO by varying structural parameter for the "box" of the SLICE structure and then exposing it to the same load cases and comparing to the baseline model.

TABLE OF CONTENTS

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I. INTRODUCTION

A. BACKGROUND

The overall purpose of this thesis is to investigate the structural aspects of a novel hull design by Lockheed under contract to the Office of Naval Research called SLICE (Advanced Technology Demonstration - ATD). The tool used for the investigation of the SLICE structure was MAESTRO. MAESTRO (The Method for Analysis, Evaluation, and Structural Optimization) is a finite element-PC based analysis tool designed to facilitate the modeling of ocean engineering structures, including ships. The SLICE ship hull is a geometrically innovative design that is a modification of the SWATH hullform.

To begin, the SWATH structure must be defined. SWATH is an acronym for Small - Waterplane - Twin - Hull. The SWATH ship can be described as a pair of torpedo-like hulls submerged underwater, and connected through the water surface to a box-like structure by one or two struts per hull which present a smaller waterplane area to dynamic wave actions than conventional monohull ships. SWATH ships are buoyantly supported vehicles with most of the buoyancy located in twin hulls below the water surface.

The low waterplane area ship concept is not new, with the first patents issued about the turn of the century. It was not until the early 1970s that the United States Navy launched the SSP Kaimalino. SSP stands for semi-submerged platform. Since then, SWATH development in various companies in Japan and the United States has resulted in a number of technically advanced designs as well as the development of a comprehensive design and performance prediction data base.

B. SWATH ADVANTAGES

The SWATH ship has several operational advantages compared to regular displacement ships, and Catamarans. Figure 1 from Gupta [Ref. 1], shows the

fundamental characteristic of the monohull, catamaran, and SWATH hull forms. The SWATH ship design has been found to be more seakindly than the conventional monohulls.

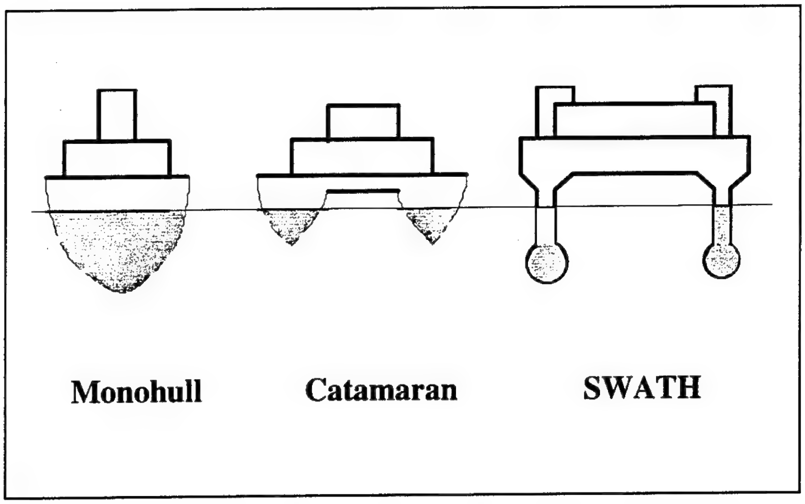

Figure 1. From Ref. 1, Comparison of Geometric Features.

Like the submersible platforms used in the offshore oil industry, SWATH ships provide a platform relatively isolated from the effects of ocean-surface disturbance. Although the additional wetted surface area of the SWATH leads to higher frictional resistance values for a given displaced volume, the smaller waterplane area tends to reduce wave making resistance especially at high speeds. The low waterplane area and the fact that much of the ship's volume is well above the water in a box-like bridge structure means that there will be little effect on speed and motions from a seaway. The large box structure leads to efficient utilization of the payload space due to the rectangular plan of the spaces. The large box also provides large deck areas for other vital shipboard operations such as helicopter landings or the addition of different mission dependent equipment packages. Other significant advantages over monohulls and catamarans include the following:

- Reduced deck wetness
- Reduced slamming in waves
- Excellent low speed maneuvering and coursekeeping

- Reduced pitch and heave.

C. SWATH PRIMARY AND SECONDARY LOADS

The primary seaway loading for a monohull is a wave induced vertical bending moment that is most severe in head seas and results in longitudinal stresses which can be predicted using classical beam theory. But according to Sikora and Dinsenbacher [Ref. 2], for the SWATH structure, the primary loading is a transverse bending moment which simultaneously flexes the struts inboard toward each other and then pries them apart. These bending moments are most severe in beam seas, and the resulting transverse stresses have been found not to behave in a classical manner. Also, secondary loads are caused by slam impacts and wave slapping. Monohulls experience these loads on the bow in head seas and SWATH ships experience these loads due to the wave action of the water entrapped between the hulls which impacts the underbody with local slam pressures. Definitively, the most significant wave-induced loads on SWATH ships are side forces which, as stated earlier, squeeze the lower hulls towards each other and then pry them apart. Beam seas produce the most severe side force. The side force creates a transverse bending moment acting on the cross-structure causing the main deck to be in tension during the squeezing cycle (transverse hogging) and in compression during the prying cycle (sagging) . The second most significant seaway loading is a yaw torsional moment.

Also, Sikora and Dinsenbacher [Ref. 2] stated that the longitudinal distribution of side forces can be assumed to be trapozoidal from bow to stern. A forward eccentricity of the trapezoid produces a "toe-in" of the lower hulls while an aft eccentricity of the trapezoid produces a "toe-out."

D. SWATH AND SLICE DIFFERENCE

The major difference between the SWATH and the SLICE is the separation of the long continuous submerged hull in the latter. This is accomplished by taking the long continuous SWATH submerged hulls and splitting them into shorter, wider hulls. This results in the SLICE ship design with four hulls and four struts. Figure 2, illustrates the geometrical difference between the SLICE and SWATH.

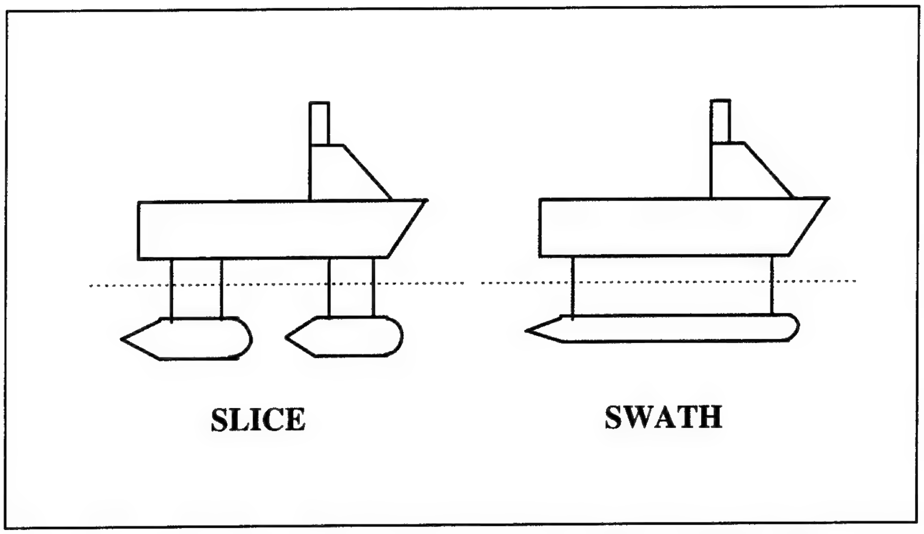

Figure 2. Geometric comparison between SLICE and SWATH.

For the SLICE structure which is the subject of this thesis, the forward hulls are offset inboard from the aft hulls to reduce interference. The SLICE is assumed to have the same operational advantages described above for the SWATH.

1. Other SLICE Advantages

The assumed primary advantage of a SLICE hull over a conventional SWATH is in its ability to maintain higher speeds due to decreased resistance. The SLICE is designed to reach speeds up to 33 knots in sea state 5. The theory is to get over the "hump" in the Resistance Coefficient verses Froude Number curve, which occurs at a Froude number of about 0.44. At a Froude number of 1.5, the resistance is considerably

Froude number of about 0.44. At a Froude number of 1.5, the resistance is considerably reduced. For a given velocity, the hull form required to get this Froude number is a short hull. The equation for the Froude Number is as follows:

$$Froude\# = \frac{V}{gL} \tag{1}$$

where V is the velocity, g is the acceleration due to gravity, and L is the length of the hull.

2. Structures

As stated earlier, the primary loading of a SWATH hull is a transverse bending moment. But in the SLICE structure, the lateral projected area is smaller than an equivalent SWATH. Therefore, the transverse bending moment of the SLICE is smaller than the SWATH. Also, the continuous underwater hull that offers large longitudinal rigidity for the SWATH does not exist for the SLICE. The main structural concern for this work is both the longitudinal and transverse loads. The lack of longitudinally continuous hulls presents the risks, of the need for excessive "box" scantlings. The transverse structure becomes a concern due to the fact that the forward and after strut/hull assemblies are free to try to move laterally in opposite directions. This latter effect opens the possibility of severe torsional loads midship on the box where heavy stress from longitudinal loading is already a concern.

In this work, the program MAESTRO is used to find the structural response to various wave loading conditions. Chapter II describes the program MAESTRO and a brief description of the finite element method employed by MAESTRO. Chapter III presents the structural stress results due to the various wave conditions imposed on the SLICE model. Chapter IV summarizes the conclusions and provides recommendations for follow on work.

II. WORKING WITH MAESTRO

A. DESCRIPTION OF MAESTRO

The Method for Analysis, Evaluation, and Structural Optimization (MAESTRO) is a finite element-based computer analysis tool, designed specifically to facilitate the modeling of large, complex thin-walled structures. The primary purpose of MAESTRO is for design, but it can be used to analyze an existing structure using the analysis and evaluation portions of the program. MAESTRO is a rationally based analysis tool, in that it is based on the limit-state approach to structural design as described by Hughes [Ref. 3]. MAESTRO was developed for Hughes as a computerized version of his design method. According to Hughes, a structural design that does not reach any limit states due to the maximum expected loads is satisfactory.

B. PRINCIPLE FEATURES OF MAESTRO

MAESTRO structural modeling is organized in four levels: members (elements), strakes, modules and substructures.

1. Elements

Since MAESTRO is only intended for preliminary design and not for detail design, the basic unit of structural modeling is a principal member such as a beam, stiffened panel, girder, or pillar. The finite elements in MAESTRO are the same as the principal members. Therefore, the elements are relatively large. Usually, an element comprises a complete panel from one deck to another. Also, the stiffened panel elements contain only in-plane stiffness and plate bending and stiffener bending are not modeled explicitly. Stiffener bending stresses are calculated using classical beam theory.

2. Strakes and Modules

The geometry of the structure dictates the number and size of the modules. A module is a portion of the structure whose lengthwise extent is divided by regularly spaced transverse planes or sections. These make up the boundaries of some or all the

individual structural members. Thin-walled structures make up modules. The thin walls need some sort of framing system to support them and some sort of local stiffeners to prevent buckling. Therefore, a large structure with a varying diverse geometry such as the SLICE is made up of many different modules joined together. The objects that make up a module are defined as strakes. A strake can be any of the following:

- flat or cylindrical
- parallel to the module axis
- plane or twisted
- prismatic or tapered
- longitudinally or transversely stiffened.

The modules are joined together in many ways to form substructures which form the complete MAESTRO model. Each module is defined, and evaluated separately, so the input and output data files are organized according to the modules. This means that each module has its own three-dimensional nodal mesh. This mesh is generated by specifying the location of endpoints in a transverse plane. The y -- z plane is the transverse plane and the x direction is in the longitudinal direction of the structure. The end planes are referred to as the *reference plane* and the *opposite plane*. For a tapered module, endpoints must be defined in both of these planes. The program then builds geometrically similar transverse planes, called sections. These sections are constant in spacing. Each section contains nodes corresponding to the endpoints. After the nodal mesh has been defined, strakes are then created by specifying the pair of endpoints which are in line with the sides of the strake. Strakes and sections are numbered sequentially. The program uses the terms "strake", "endpoint", "section", and "module" to refer to certain locations within the structural model. Each strake extends for the full length of the module. Since each module has constant section spacing, two or more compartments with the same frame spacing can be grouped together in one module.

3. Substructures

Due to centerline symmetry, only half of the SLICE structure was modeled. A total of seven substructures and 26 modules were needed to model the SLICE. Substructures one and two represent the box of the SLICE structure. Substructures four and six represent the pods and substructures five and six represent the struts. As mentioned earlier, a series of modules define a substructure. Unfortunately, the user is limited to the number of substructures and modules which can be handled by the version of MAESTRO. For this work, the professional version of MAESTRO 6.2 was limited to a maximum of 10 substructures and 60 modules. This limits a substructure to only six modules. Also included with MAESTRO is a graphical program MG (MAESTRO GRAPHICS) which allows the user to verify that the model is being modeled correctly. The version of MG that was utilized allowed up to 100 modules so there no constraints on our model of the SLICE (ATD). After a successful run, MG graphically illustrates the results due to the different load cases imposed on the model. The MAESTRO method of design is referred to as "rationally-based" because it features a rapid, "design-oriented" finite element analysis which uses elements that are exactly suited for preliminary design. The program also conducts an explicit evaluation of all limit states (ultimate strength and unserviceablity), at both the levels of the member and module for all loadcases. This establishes the limiting states, which are critical for each evaluated member in each module.

After each finite element analysis, the structure is thoroughly checked for all of the various modes and levels of failure, and other limit states, and the structure's degree of adequacy for each of these is calculated and expressed in the form of an "adequacy parameter".

The program also creates various data files most needed for the MG program. One of the files created is the OUT file. This file is usually quite extensive. For the work in this thesis, the OUT file is well over 2,500 pages.

C. BRIEF DESCRIPTION OF THE FINITE ELEMENT METHOD USED IN MAESTRO

Since MAESTRO uses parts of the structure as the defined elements, the mesh generated is very coarse. This definitely limits the accuracy of any of the results. But for an initial design, MAESTRO models the entire structure and the combinations of effects can be seen. According to Hughes [Ref. 3], the basic concept of the finite element method is to represent the structure as an assemblage of individual structural elements interconnected at a discrete number of nodes. So in a continuous structure such as a panel of plating, a corresponding natural subdivision does not exist and it is necessary to divide the plating artificially into a number of elements connected at their respective nodes. These elements are called "finite elements" and are usually rectangular or triangular in shape. To use matrix or basic methods, the essential requirement is that the structural continuum must be represented in terms of a finite number of discrete variables. These variables are the nodal displacements. In terms of nodal displacements, the essential requirement is that the internal displacements of the elements must be related to the nodal displacements and all of the interactions of the elements must be expressed in terms of nodal displacements. So the only unknowns in the problem are the nodal displacements and the problem becomes discrete rather than continuous. Even though there may be a large number of nodal displacements, there are only a discrete number of variables that are interrelated by linear equations and can be handled by the basic method. Also, to achieve an exact solution, the finite element representation needs to satisfy the requirements of equilibrium and geometric compatibility everywhere, both within and between elements.

In MAESTRO, Hughes only considers the two-dimensional plane stress elements for elements of ship structural analysis and design. For panels and shells that have only slight curvature, again only plane stress elements are considered. Hughes defines the five basic steps that are unique to MAESTRO, in the derivation of the stiffness matrix of a rectangular plane stress element. Since a rectangle has two sides *a* and *b* and there are

two degrees of freedom at each node, the element will have eight degrees of freedom or nodal displacements which in the matrix form are:

$$\delta = \begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{bmatrix} \tag{2}$$

1. Step One

Step one is selecting the suitable displacement function. Since the rectangular element has eight degrees of freedom, then eight unknown coefficients in the polynomial representing the displacements must be used. The following are the polynomial equations:

$$u(x, y) = c_1 + c_2 x + c_3 y + c_4 xy \tag{3}$$

$$v(x, y) = c_5 + c_6 x + c_7 y + c_8 xy\,. \tag{4}$$

From the above equations it can be seen that when x is constant both u and v vary linearly with y, and also when y is constant both displacements vary linearly with x. The displacements thus vary linearly along each side of the element. Since the displacements of two adjacent elements must be equal at their common nodes, the displacements will also be equal along the entire common boundary. The following equation is the same as Equations (3) and (4) but in matrix form:

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{bmatrix} 1 & x & y & xy & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x & y & xy \end{bmatrix} \begin{Bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \end{Bmatrix} \tag{5}$$

or

$$\delta(x,y) = \boldsymbol{H}(x,y)\boldsymbol{C}. \tag{6}$$

2. Step Two

Step two is to relate the general displacement within the element to the nodal displacements. This step is achieved by substituting the values of the nodal coordinates into Equation (5) once for each node (four times) and then solving for C. The substitution yields:

$$\delta = AC \tag{7}$$

or

$$\delta = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & a & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & a & 0 & 0 \\ 1 & a & b & ab & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & a & b & ab \\ 1 & 0 & b & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & b & 0 \end{bmatrix} C. \tag{8}$$

Solving for C yields:

$$C = A^{-1}\delta \tag{9}$$

or

$$C=\frac{1}{ab}\begin{bmatrix} ab & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -b & 0 & b & 0 & 0 & 0 & 0 & 0 \\ -a & 0 & 0 & 0 & 0 & 0 & a & 0 \\ 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 \\ 0 & ab & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -b & 0 & b & 0 & 0 & 0 & 0 \\ 0 & -a & 0 & 0 & 0 & 0 & 0 & a \\ 0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 \end{bmatrix}\delta, \qquad (10)$$

and from Equation (6), the general displacement in terms of the nodal displacements is

$$\delta(x,y)=\boldsymbol{HA}^{-1}\delta. \qquad (11)$$

Next, we need to evaluate the product $\boldsymbol{HA}^{-1}$ to obtain an explicit expression for the element internal displacement $\delta(x,y)$ in terms of the nodal displacements. Substituting for $\boldsymbol{H}$ and $\boldsymbol{A}^{-1}$ and multiplying them gives

$$u(x,y) = (1-\xi)(1-\eta)u_1+\xi(1-\eta)u_2+\xi\eta u_3+(1-\xi)\eta u_4 \qquad (12)$$

$$v(x,y) = (1-\xi)(1-\eta)v_1+\xi(1-\eta)v_2+\xi\eta v_3+(1-\xi)\eta v_4 \qquad (13)$$

where $\xi= x/a$ and $\eta= y/b$.

3. Step Three

Step three is to express the internal deformation (strains) in terms of the nodal displacements. From the following equations, the definition of strain in a two-dimensional element is defined.

$$\varepsilon_x = \frac{\partial u}{\partial x} \qquad (14)$$

$$\varepsilon_y = \frac{\partial v}{\partial y} \qquad (15)$$

$$\gamma = \frac{\partial u}{\partial y}+\frac{\partial v}{\partial x} \qquad (16)$$

Substituting for u and v from Equation (5) and differentiating, results in the following equation:

$$\varepsilon(x,y)=\begin{bmatrix}0&1&0&y&0&0&0&0\\0&0&0&0&0&0&1&x\\0&0&1&x&0&1&0&y\end{bmatrix}C \tag{17}$$

or

$$\varepsilon(x,y)=GC \tag{18}$$

If we substitute for C from Equation (10) and introduce the strain matrix, $\boldsymbol{B}$

$$B = GA^{-1} \tag{19}$$

in terms of Equation (17) results in the following equation

$$\varepsilon(x,y)=B\delta\,. \tag{20}$$

After solving for B, the strain matrix is found to be:

$$B=\frac{1}{ab}\begin{bmatrix}-b+y&0&b-y&0&y&0&-y&0\\0&-a+x&0&-x&0&x&0&a-x\\-a+x&-b+y&-x&b-y&x&y&a-x&-y\end{bmatrix} \tag{21}$$

4. Step Four

Step four is to express the internal force (stress) in terms of nodal displacements, using the element's law of elastic behavior. Stress is obtained from

$$\sigma = D\varepsilon \tag{22}$$

where D is defined as:

$$D=\frac{E}{1-\nu^2}\begin{bmatrix}1&\nu&0\\\nu&1&0\\0&0&\dfrac{1-\nu}{2}\end{bmatrix} \tag{23}$$

After substituting for $\varepsilon(x,y)$ from Equation (20), the following equation is obtained.

$$\sigma(x,y)=DB\delta \tag{24}$$

5. Step Five

The final step in the process is to obtain the element stiffness matrix by relating nodal forces to nodal displacements. The element stiffness matrix is given by the following equation:

$$k^e = t\left[\int_0^b\int_0^a B^T DB dxdy\right] \tag{25}$$

Since B contains both x and y terms, the B^TDB must be evaluated first, and then the resulting matrix must be integrated over the area of the element. In order to simplify the stiffness matrix, it is preferred to present the result in two parts:

$$k^e = k_\varepsilon + k_\gamma \tag{26}$$

where

$$k_\varepsilon = \frac{Et}{12(1-\nu^2)}\begin{bmatrix} \frac{4}{\alpha} & & & & & & & \\ 3\nu & 4\alpha & & & & & & \\ \frac{-4}{\alpha} & -3\nu & \frac{4}{\alpha} & & & & & \\ 3\nu & 2\alpha & -3\nu & \frac{4}{\alpha} & & & & \\ \frac{-2}{\alpha} & -3\nu & \frac{2}{\alpha} & -3\nu & \frac{4}{\alpha} & & & \\ -3\nu & -2\alpha & 3\nu & -4\alpha & 3\nu & 4\alpha & & \\ \frac{2}{\alpha} & 3\nu & \frac{-2}{\alpha} & 3\nu & \frac{-4}{\alpha} & -3\nu & \frac{4}{\alpha} & \\ -3\nu & -4\alpha & 3\nu & -2\alpha & 3\nu & 2\alpha & -3\nu & 4\alpha \end{bmatrix} \tag{27}$$

in which $\alpha = a/b$ and

$$k_{\gamma} = \frac{Et}{24(1+\nu)} \begin{bmatrix} 4\alpha & & & & & & & \\ 3 & \frac{4}{\alpha} & & & & & & \\ 2\alpha & 3 & 4\alpha & & & & & \\ -3 & \frac{-4}{\alpha} & -3 & \frac{4}{\alpha} & & & & \\ -2\alpha & -3 & -4\alpha & 3 & 4\alpha & & & \\ -3 & \frac{-2}{\alpha} & -3 & \frac{2}{\alpha} & 3 & \frac{4}{\alpha} & & \\ -4\alpha & -3 & -2\alpha & 3 & 2\alpha & 3 & 4\alpha & \\ 3 & \frac{2}{\alpha} & 3 & \frac{-2}{\alpha} & -3 & \frac{-4}{\alpha} & -3 & \frac{4}{\alpha} \end{bmatrix}. \qquad (28)$$

D. BUILDING OF SLICE MODEL

1. Description of SLICE (ATD) Model

The following is the configuration of the SLICE structure:

- Displacement - 160 L. Tons
- Length Overall - 105 feet
- Beam - 52 feet
- Payload Capacity- 30 L. Tons
- Material - 5083 Aluminum Alloy
- Yield Stress (as welded) 24 KSI
- Ultimate Stress (as welded) 39 KSI.
- Design Water Line 15 feet
- Moulded Depth 27 feet

Figure 3, illustrates the unique SLICE structure used in MAESTRO. The structure consists of the "box", "four struts", and the "four submarine shaped pods". The plate thickness varies throughout the structure. For the entire box and pods, the plate thickness is 0.25 inches. For the load carrying strut assemblies, the plate thickness is 0.87 inches as dictated by the initial SLICE drawings from Lockheed. Transverse stiffeners throughout the structure adhere to Nappi's [Ref. 7] recommended breadth to depth ratio of 1/2. The

dimensions for the stiffeners is as follows: breadth - 3 inches, depth - 6 inches, web - 0.25 inches. The geometry of the forward pods is as follows: the forward pod - 33 feet in total length, and the after pod - 36 feet in total length. The largest diameter of both pods is eight feet at the midlength. The struts are four feet in width and are tapered forward and aft.

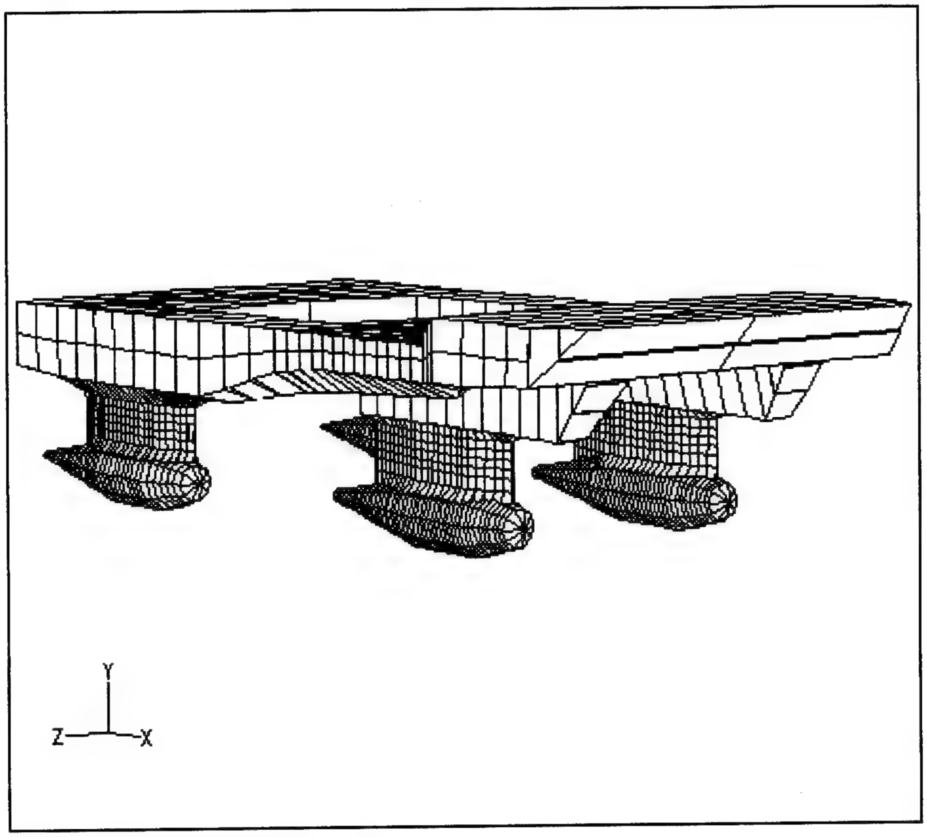

Figure 3. SLICE Structure.

2. Description of MAESTRO Input File

The characteristics of a structure to be modeled in MAESTRO must be placed in an input file with a ".DAT" extension. The following discusses only the more important groups needed for the SLICE input file. Appendix A contains the detailed development of SLICE.

Both the limitation of number of modules/substructures and the SLICE's diverse geometry require to separating the structure into seven substructures and 26 modules. The geometry of the "box" produced the same kind of input data file format for all of the modules in the first three substructures. The format of the input data file for each module begins by defining the frame spacing, starting position, and number of sections. The hull plating geometry is established in data group II by the endpoints. The "strakes" in data group IV (a) are defined next. For all of the modules, with the exception of the "submarine shaped pods", the "strakes" were simple straight panel shell elements. A different type of "curved strake" was needed for the "submarine shaped" pods. If any transverse bulkheads were needed, then a superelement will be defined in group IV (b). The plating scantlings and stiffeners are specified in data group IX. The frame scantlings are specified in data group XI. Since the "box" consisted of only shell plating and transverse stiffeners, groups XIII - XV were not needed. Group XVII joined the modules within the substructure.

The pattern to follow for the input data file is as follows: define the substructure followed by defining the modules within that substructure, then define the next substructure and its modules, etc., until all substructures and modules were defined.

Next all of substructures and modules need to be joined together. This is followed by defining all of loads both static and dynamic. Appendix A contains a table showing all of static loads for the SLICE. The boundary conditions and constraints must be applied next. For this model, the constraints were applied on the model's centerline. For this work, a total of six different static/wave conditions were imposed on the model.

III. RESULTS AND DISCUSSION FROM MAESTRO

A. DESCRIPTION OF APPLIED LOADS

Since the SLICE does not have the long continuous underwater hull that offers the large longitudinal rigidity of SWATH, the main structural concern is both the transverse and longitudinal loads. The SLICE transverse structure becomes a concern due to the fact that the forward and after strut/hull assemblies are free to try to move laterally in opposite directions. This latter effect opens the possibility of severe torsional loads midship. The SLICE is designed to maintain 33 knots at sea state 5. The SLICE model was exposed to six different wave load conditions. Three wave load conditions were applied at sea state 5. To increase the forces on the SLICE structure, the remaining three wave load conditions were applied at sea state 8. Within each sea state, the wave amplitude and wave length were constant. Only the locations of the wave/structure interaction werevaried. Figure 4 shows the wave/structure interaction.

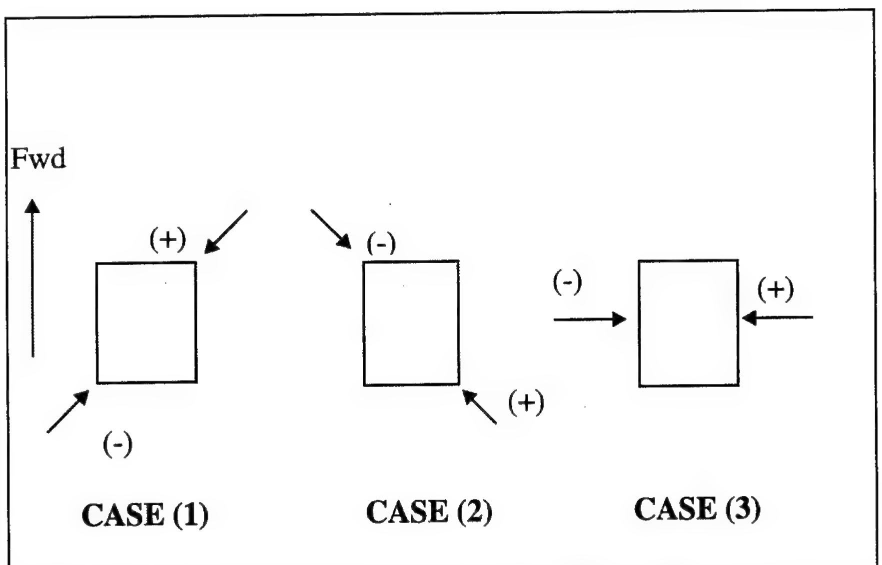

Figure 4. Wave/SLICE Structure Interaction.

In all of the finite element runs, the model was stationary not making way, and the only loads applied were the static and the dynamic wave loads. The following illustrates the different cases for both sea state 5 and sea state 8:

- Case (1) - A sea state 5 wave's crest is located off the model's starboard bow, and the wave's trough is off the port quarter.
- Case (2) - A sea state 5 wave's crest is located off the model's starboard quarter, and the wave's trough is off the port bow.
- Case (3) - A sea state 5 wave's crest is off the starboard beam, and the wave's trough is off the port beam.
- Case (4) - A sea state 8 wave's crest is located off the model's starboard bow, and the wave's trough is off the port quarter.
- Case (5) - A sea state 8 wave's crest is located off the model's starboard quarter, and the wave's trough is off the port bow.
- Case (6) - A sea state 8 wave's crest is off the starboard beam, and the wave's trough is off the port beam.

In MAESTRO, the wave loads simulating the different sea states are generated by inputting the amplitude and wave lengths. For sea state 5 with a period of 5.8 sec., a wave of amplitude of 10 ft and a wave length of 172.3 ft were input. Sea state 8 with a period of 12.9 sec. was defined by an amplitude of 50 ft and wave length of 852.1 ft.

According to Sikora, Kennel, and Gore [Ref. 2, Ref. 4, Ref. 5, and Ref. 6], case (3) and case (6) represent the worst loadcase for the typical SWATH structure. Case (3) and case (6) represent the beam sea which provides the maximum prying side force. One aspect of this work is to verify whether this assumption is valid for the SLICE structure. Another aspect is to verify how the structure is affected by the splitting moment from cases (1), (2), (4), and (5). These results will be compared to the reactions from cases (3) and (6). Also to verify the validity of the MAESTRO results, two different MAESTRO runs were conducted. Both were run with all the same parameters except for different "box" stiffener sizes.

The MAESTRO tool used to verify the validity of the program and the model was the "adequacy parameters". In order to define the "adequacy parameter", the following derivation is needed to clarify the concept. The rational design aspect of MAESTRO requires a rigorous check of types of failure: plastic deformation, buckling, and fracture. It also requires, for each of these types, the explicit consideration of all of the modes in which a member, or a group of members, may fail. In each of these failure modes, failure occurs when a load effect $\boldsymbol{Q}$, in combination with other loads effects, reaches some limit value $\boldsymbol{Q_L}$. For the case of stress the load effect is expressed as σ and the limit value as σ_L. Structural safety factors specify the required margin between $\boldsymbol{Q}$ and $\boldsymbol{Q_L}$. The structural safety factor requires that each of various load effects in the structure must not exceed a certain fraction of the various limit values that pertain to that specific load effect. The fraction is given by the inverse of the combined safety factor γ:

$$\gamma \boldsymbol{Q} < \boldsymbol{Q_L} . \tag{29}$$

The "strength ratio" $\boldsymbol{R(x)}$ is expressed from:

$$R(X) = \frac{Q(X)}{Q_L(X)} \tag{30}$$

which simplifies to

$$\gamma \boldsymbol{R(X)} < \boldsymbol{1}. \tag{31}$$

Each of the requirements constitutes a constraint on the design. In MAESTRO each constraint is expressed in the form

$$\boldsymbol{g(R) > 0} \tag{32}$$

in which $\boldsymbol{g(R)}$ is an "adequacy parameter" which is defined as

$$g(R) = \frac{1-\gamma R}{1+\gamma R} \quad . \tag{33}$$

The "adequacy parameter" $\boldsymbol{g(R)}$ ranges in value between ± 1. An "adequacy parameter" of +1 is considered satisfactory while an "adequacy parameter" -1 is unsatisfactory. The following are the selected "adequacy parameters" for the panel element which will be used in verifying MAESTRO's results:

- Transverse Plate Bending (PSPBT)
- Longitudinal Plate Bending (PSPBL)
- Local Buckling Panel Failure (PFLB).

Transverse and longitudinal plate bending is predicted by the use of the distortion energy criterion:

$$R_{PSPBT} = \frac{\gamma_S \sigma_{VM,T}}{\sigma_Y} \qquad (34)$$

and

$$R_{PSPBL} = \frac{\gamma_S \sigma_{VM,L}}{\sigma_Y} \qquad (35)$$

where

σ_{vmT} = Von Mises equivalent stress at the midlength of the transverse edge

σ_{vmL} = Von Mises equivalent stress at the midlength for the longitudinal edge

γ_s = Load factor for seviceability.

Panel failure due to local buckling (PFLB) is defined as the limit state referring to the buckling, elastic or inelastic, of plating between stiffeners.

In addition to the "adequacy parameter", MAESTRO also calculates the plane stress matrix and Von Mises stresses. For the SLICE model, the panel element was emphasized and the stresses due to in-plane loads are defined by the plane stress matrix:

$$\sigma = \begin{bmatrix} \sigma_x & \tau_{xy} \\ \tau_{xy} & \sigma_y \end{bmatrix} . \qquad (36)$$

The Von Mises stress is expressed by

$$\sigma_e = \sqrt{\sigma_1^{\ 2} - \sigma_1\sigma_2 + \sigma_2^{\ 2}} . \qquad (37)$$

One of the properties of the MAESTRO panel element is that within each element σ_x is constant in the *x* direction and varies linearly in the *y* direction, while σ_y is constant in the

y direction and varies linearly in the x direction. The shear stress τ is constant within each element.

B. RESULTS

The plan of attack for presenting the results of the different load cases will be in accordance with the following three concerns:

- Need to verify that the splitting moment from load cases (1), (2), (4), and (5) differs from the side force from load cases (3), and (6),
- Need to determine whether the beam sea which provides the maximum prying side force for the SWATH, also applies to the SLICE structure,
- Need to validate the results from MAESTRO by changing only the "box" stiffener sizes.

1. Comparison of SLICE's Structural Stress Reaction to Different Load Cases

As stated earlier, the SLICE model was exposed to two different sea states with varying directions. Both Figure 5 and Figure 6, illustrates the σ_x stress distribution for the structure reactions to sea state 5. Figure 5 shows the SLICE's σ_x stress distribution response to case (2). Figure 6 shows the same SLICE's σ_x stress distribution for case (3). Figure 7 and Figure 8, illustrates the σ_x stress distribution for the structural response to sea state 8. Figure 7 shows the SLICE structure's response to load case (5), and Figure 8 shows the structure's response to loadcase (6). In comparing Figure 5 and Figure 6, the range of affected σ_x stress distribution is very similar for the two different cases. Also, Figure 7 and Figure 8 have similar results for the σ_x distribution.

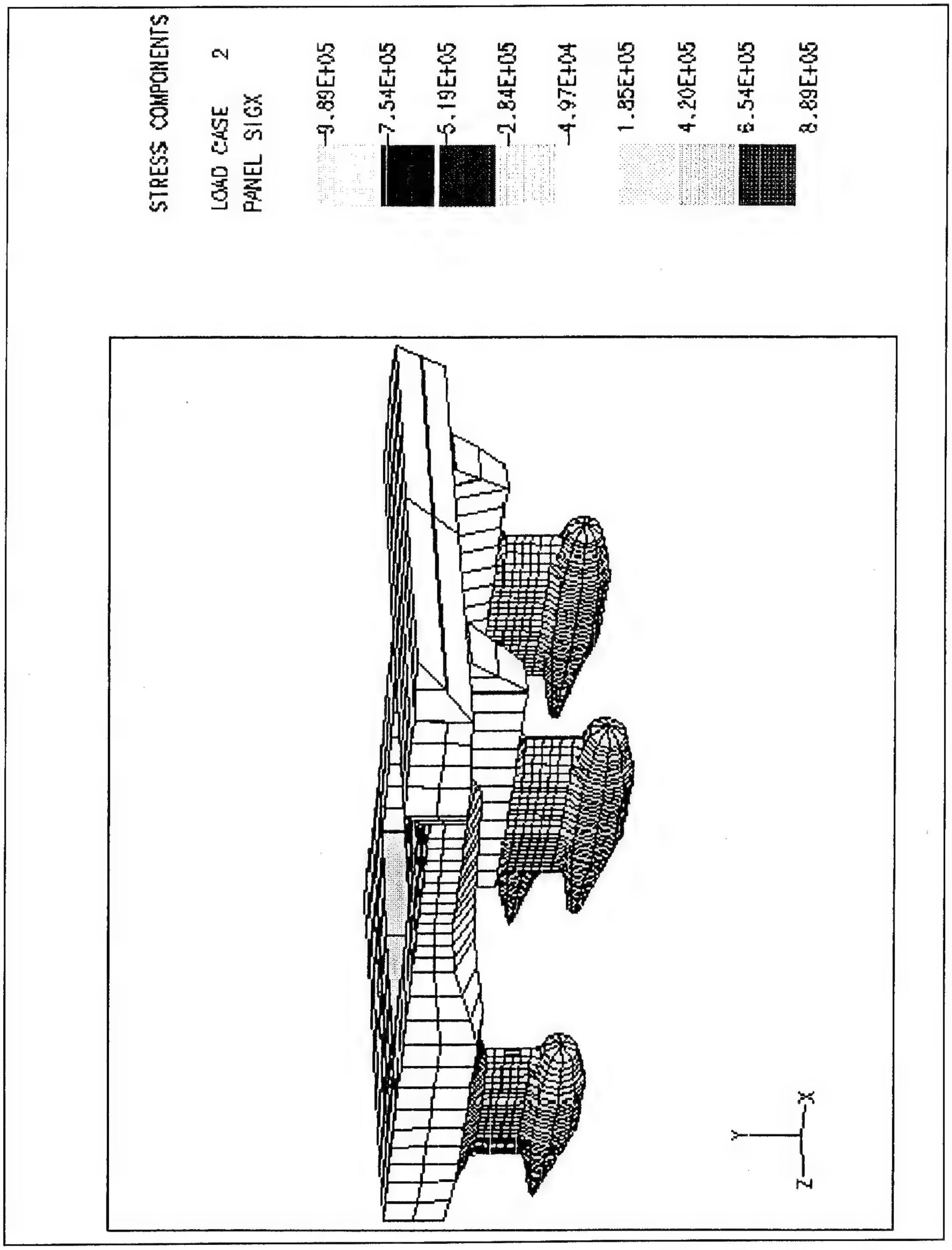

Figure 5. SLICE Structure's SigmaX stress response to case (2).

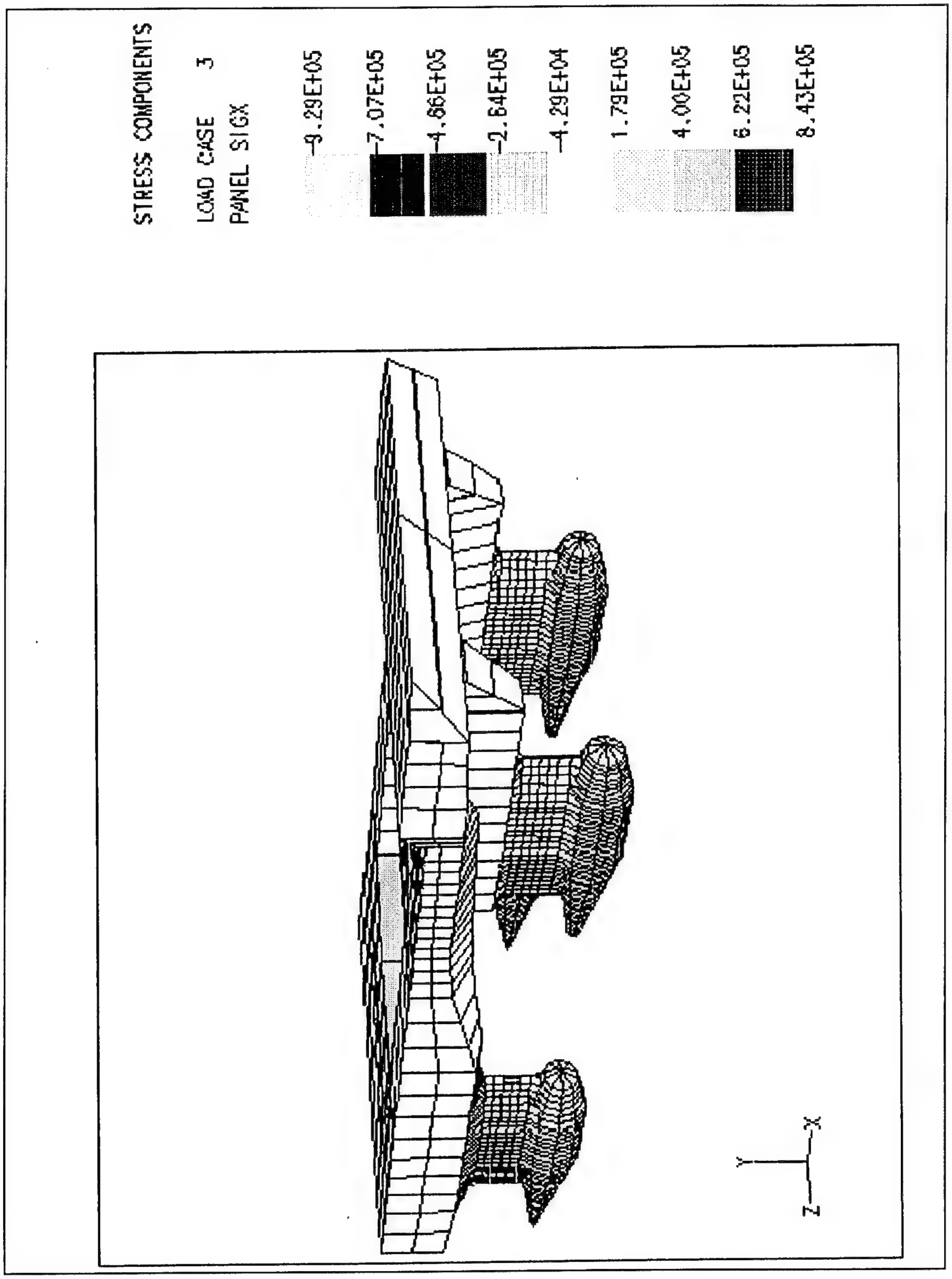

Figure 6. SLICE Structure's SigmaX stress response to case (3).

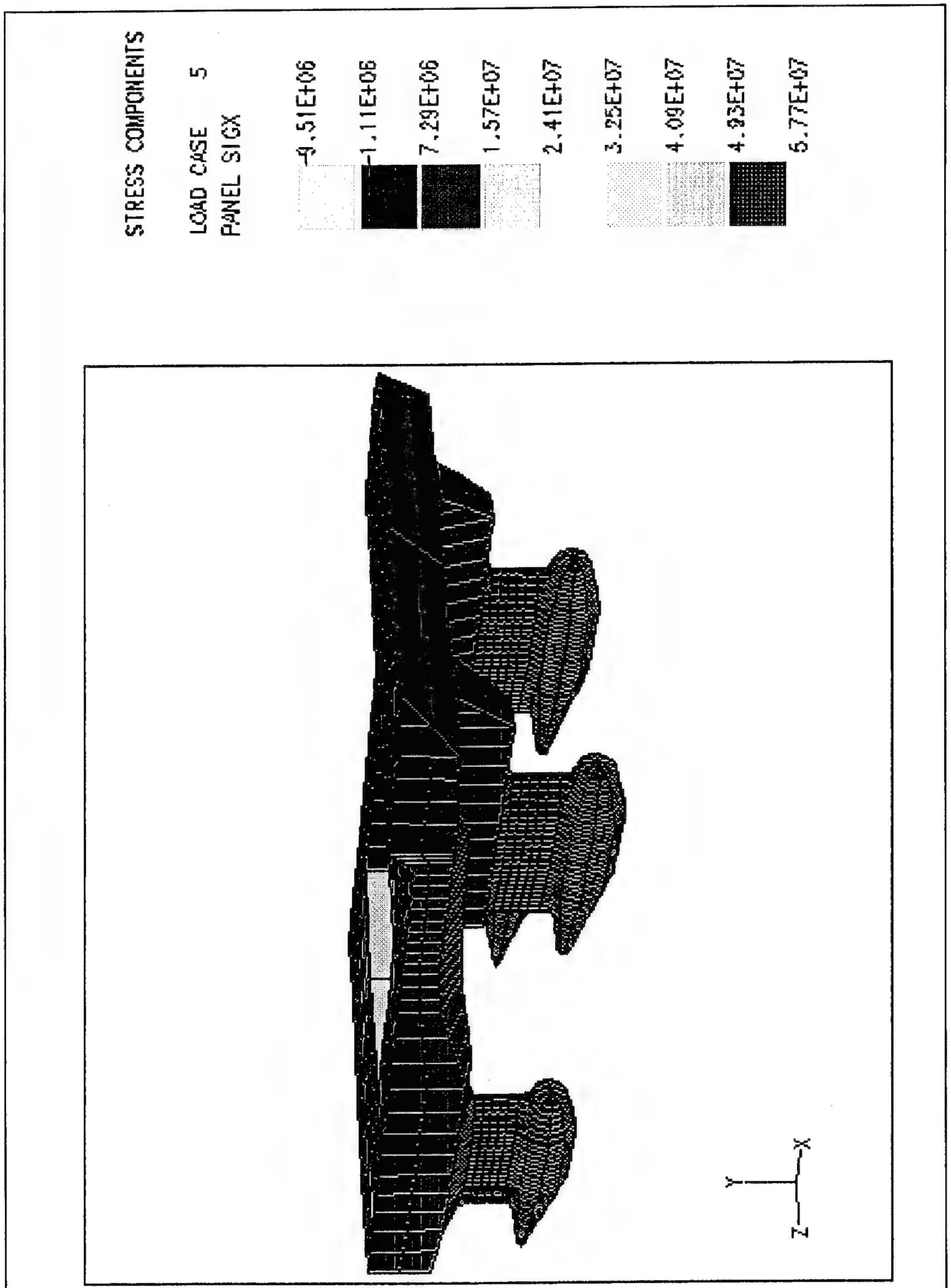

Figure 7. SLICE Structure's SigmaX stress response to case (5).

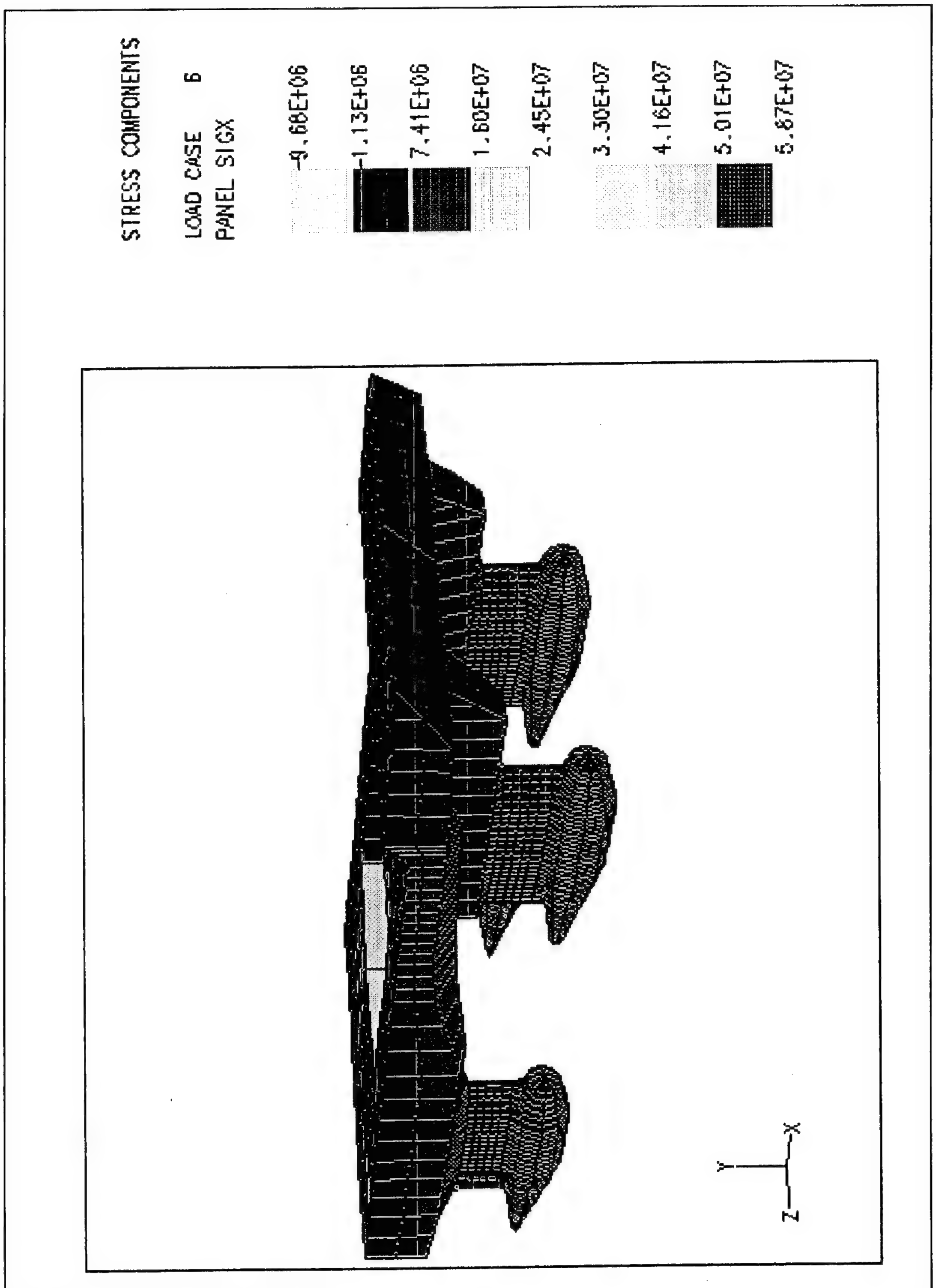

Figure 8. SLICE Structure's SigmaX stress response to case (6).

The units for all of the stresses and pressures presented in the figures are pounds per square inch. For sea state 5, the σ_x stress distribution in Figures 5 and 6 lies within the same range. This is indicated by the SLICE hull exhibiting the same shade of yellow for the elements throughout the "box" for load case (2) and case (3). Case (1) which is not shown also exhibits the same characteristics as case (2) and case (3). The only elements of varying stresses were located on the forward pod/struts assemblies.

For sea state 8, the σ_x stress distribution in Figures 7 and 8 is similar. Again, this is represented by the similar shade of blue for case (5) and case (6). Case (4) which is not shown also exhibits the same results as case (5) and case (6). For the two sea states, the only elements with different σ_x stress elements are located on the strut/pod assemblies. The obvious conclusion drawn from Figures 5, 6, 7, and 8 is that within the same sea state, the SLICE's hull geometry is insensitive to the direction of the seas. This verifies that there is a almost no difference between the splitting moments from load cases (1), (2), (4), and (5) and the side force applied from load cases (3) and (6).

2. Compare the SLICE's Structural Response to the SWATH's Structural Response to Beam Seas

According to Reilly [Ref. 8], the 3-D finite element analysis of a SWATH shows that the critical load case is the maximum side force in a beam sea. Since the SLICE lacks the continuous underwater hull, the transverse structure might exhibit severe torsional loads midships on the box. For the following, the investigation was concentrated for the beam sea/hull interaction represented by case (3) - sea state 5, and case (6) - sea state 8. The following figures will show the different stress components in reactions to the different load cases and sea states. In addition, figures of the forward pod/strut assembly showing details of the affected stressed elements will be provided. The maximum deflections for both sea state 5 and sea state 8 will be compared to Reilly's [Ref. 8] results.

The following figures show the stress distributions in response to load case (3). In Figure 9, the forward pod's σ_x stress distribution is presented. Figure 10 presents the SLICE's σ_y stress distribution. In Figure 11, the σ_y stress distribution is displayed for the forward pod/strut assemblies. Figure 12 exhibits the SLICE's shear stress. Figure 13 also presents the shear stress for the forward pod/strut assembly. The Von Mises stress distribution is presented in the SLICE structure in figure 14. In Figure15, the Von Mises stress is displayed for the forward pod/strut assembly. Figure 16 displays the panel pressure distribution for the SLICE structure.

The following figures show the stress distributions in response to load case (6). In Figure 17, the forward pod/strut assembly's σ_x stress distribution is presented. Figure 18 presents the SLICE's σ_y stress distribution. In Figures 19, the σ_y stress distribution is displayed for the forward pod/strut assembly. Figure 20 exhibits the SLICE's shear stress. The Von Mises stress distribution is presented in the SLICE structure in Figure 21. In Figure 22, the Von Mises stress is displayed for the forward pod/strut assembly. Figure 23 displays the panel pressure distribution for the entire SLICE structure.

The following is the explanation and comparison of the results between sea state 5 and sea state 8. For σ_x stress distribution, the stress is much higher in Figure 17 (sea state 8) by a factor of 100, than figure 9 (sea state 5). Both Figures 9 and 17, elements react similarly. For σ_y stress distribution, the stress is much higher in Figure 18 (sea state 8) than Figure 10 (sea state 5). Figures 11 and 19 show the σ_y stress distribution for the forward pod; the only difference is the higher stress distribution in Figure 19 due to sea state 8. Again the same set of elements in both figures show the same variations. The local shear stress element is represented in Figures 12, 13, and 20.

The most obvious difference is the magnitude of shear stress is greater in the two latter figures. The Von Mises stress is represented in Figures 14, 15, 21, and 22. Again the only difference is the magnitude which is greater in Figures 21, and 22. Figures 16 and 23 represent the panel pressure. Figure 23 (sea state 8) shows the pressures due to the hydrodynamics and static loads and represents a more realistic picture of the pressure

distribution for the SLICE substructure. Figure 16 shows that the pressure is less in sea state 5 than sea state 8. The most obvious result, between the two sea states 5 and 8, is the increase in stress and pressure distribution in the latter. Reilly [Ref. 8] demonstrated for a SWATH, the deflections for a beam sea in sea state 7 varied from 1.1 to 1.56 inches. Checking the deflection to the fore and aft pods for all of the load cases in sea state 8, the forward pod in case (6) provided the greatest deflection. For our model, a nodal point was selected from section 8, module 2, substructure 4 which is midlength on the forward pod and similar to the point selected by Reilly [Ref. 8]. The maximum deflection was 1.8 inches. Since the forward pod was impacted by a beam sea of sea state 8, a deflection greater than Reilly [Ref. 8] was expected. At the beam sea/hull interaction, the SLICE's underwater area is the greatest so reactions are most SWATH similar. The deflection, and pressure distribution proves that the SLICE's structural response is similar to the SWATH's structural response to beam seas. The box structure did not exhibit any major stressed elements for any of the load cases and sea states. Only elements on the tapered ends of the pod/strut assemblies showed variations to stress and pressure distributions. This is due to lack of stiffeners in these areas due to geometry and space constraints.

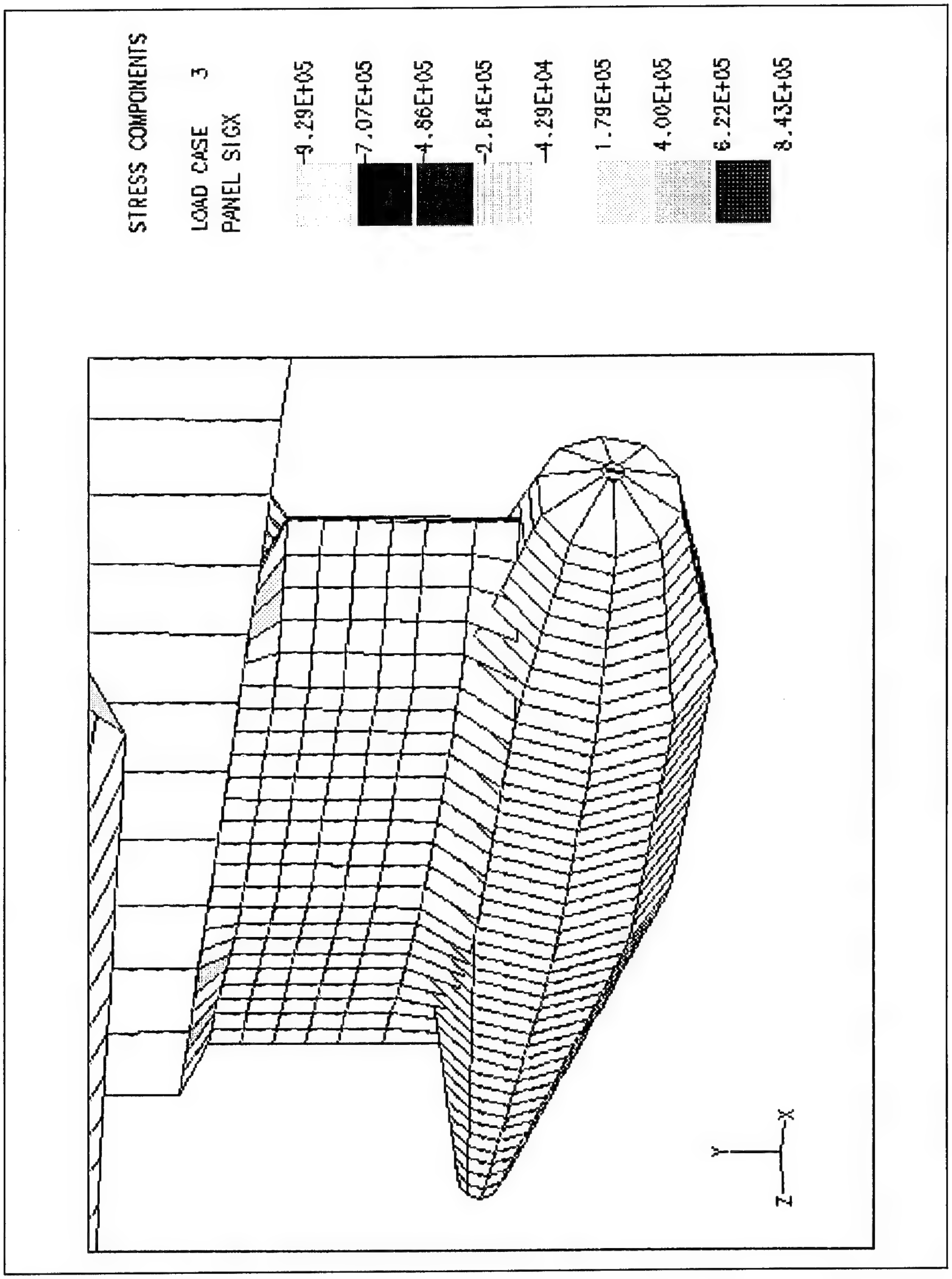

Figure 9. Forward Pod's SigmaX stress response to case (3).

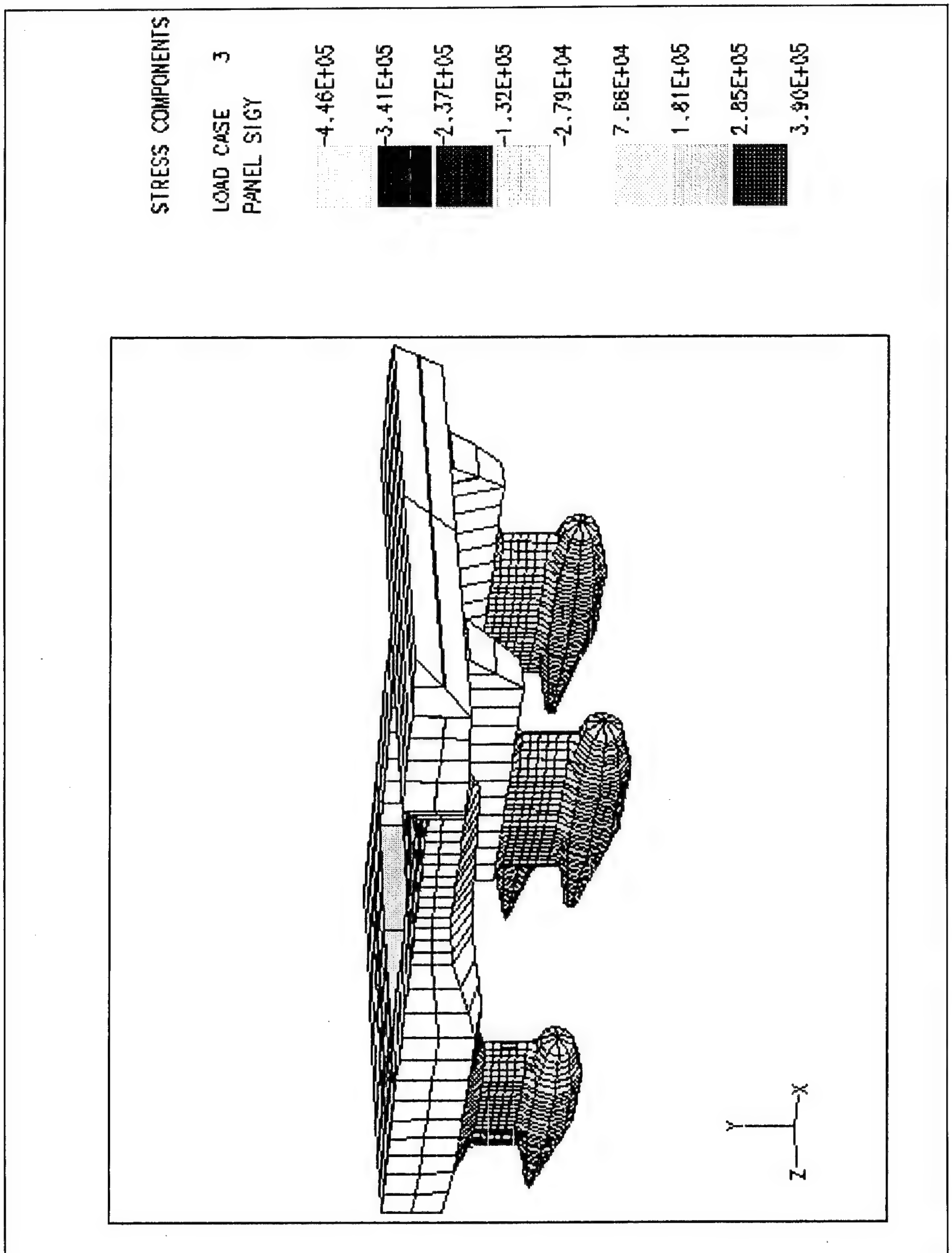

Figure 10. SLICE's Structure SigmaY stress response to case (3).

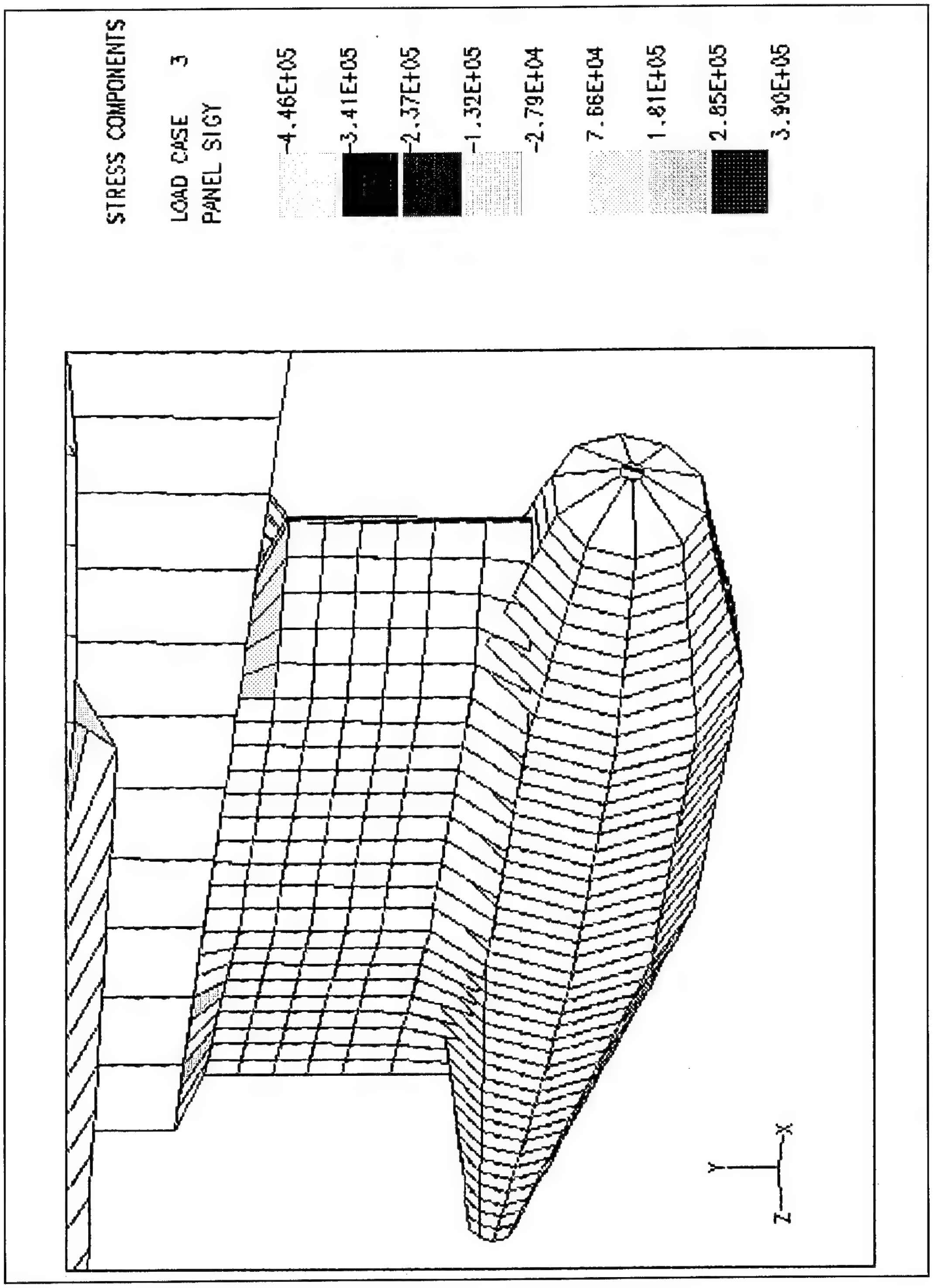

Figure 11. Forward Pod's SigmaY stress response to case (3).

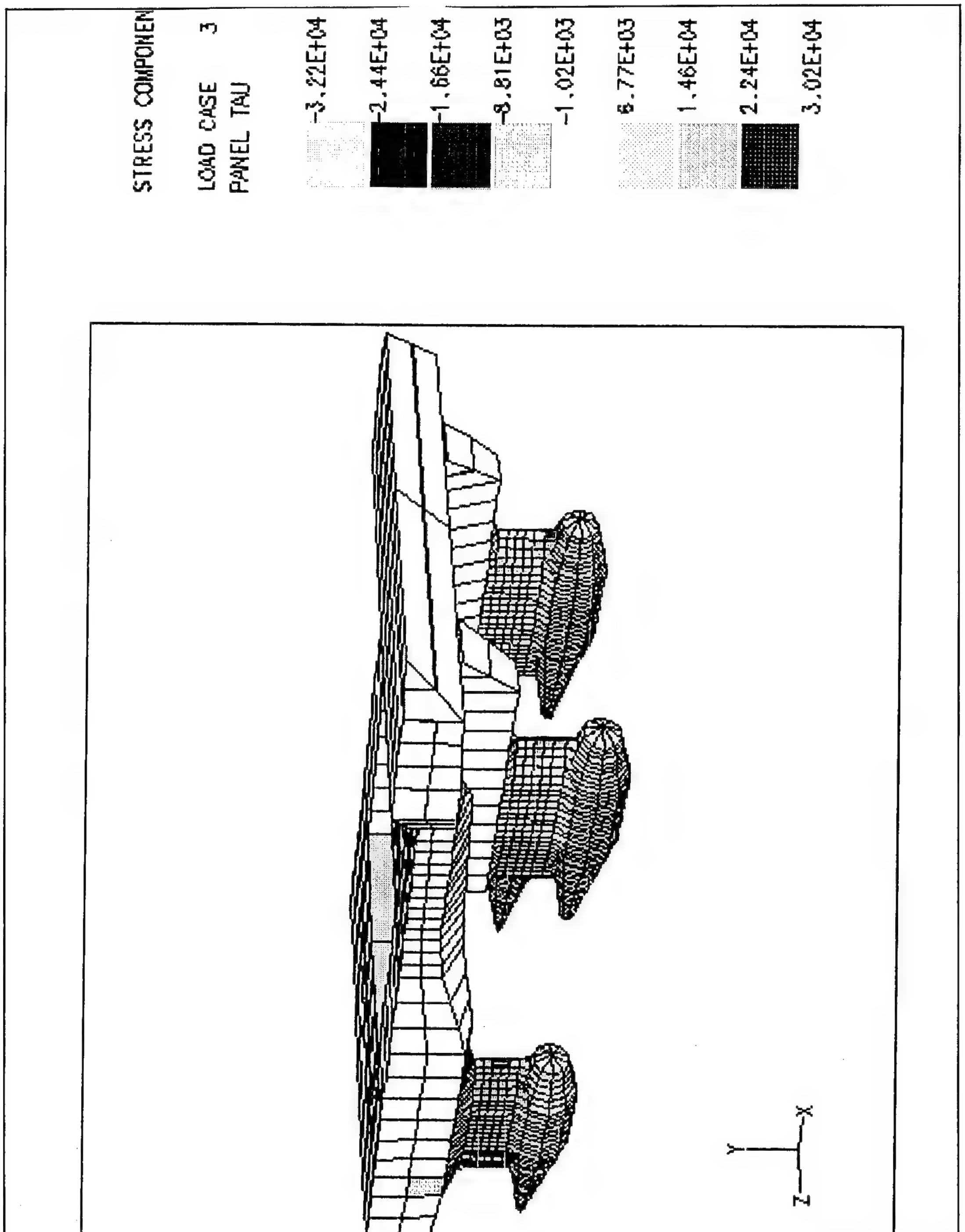

Figure 12. SLICE's Shear Stress Response to Case (3).

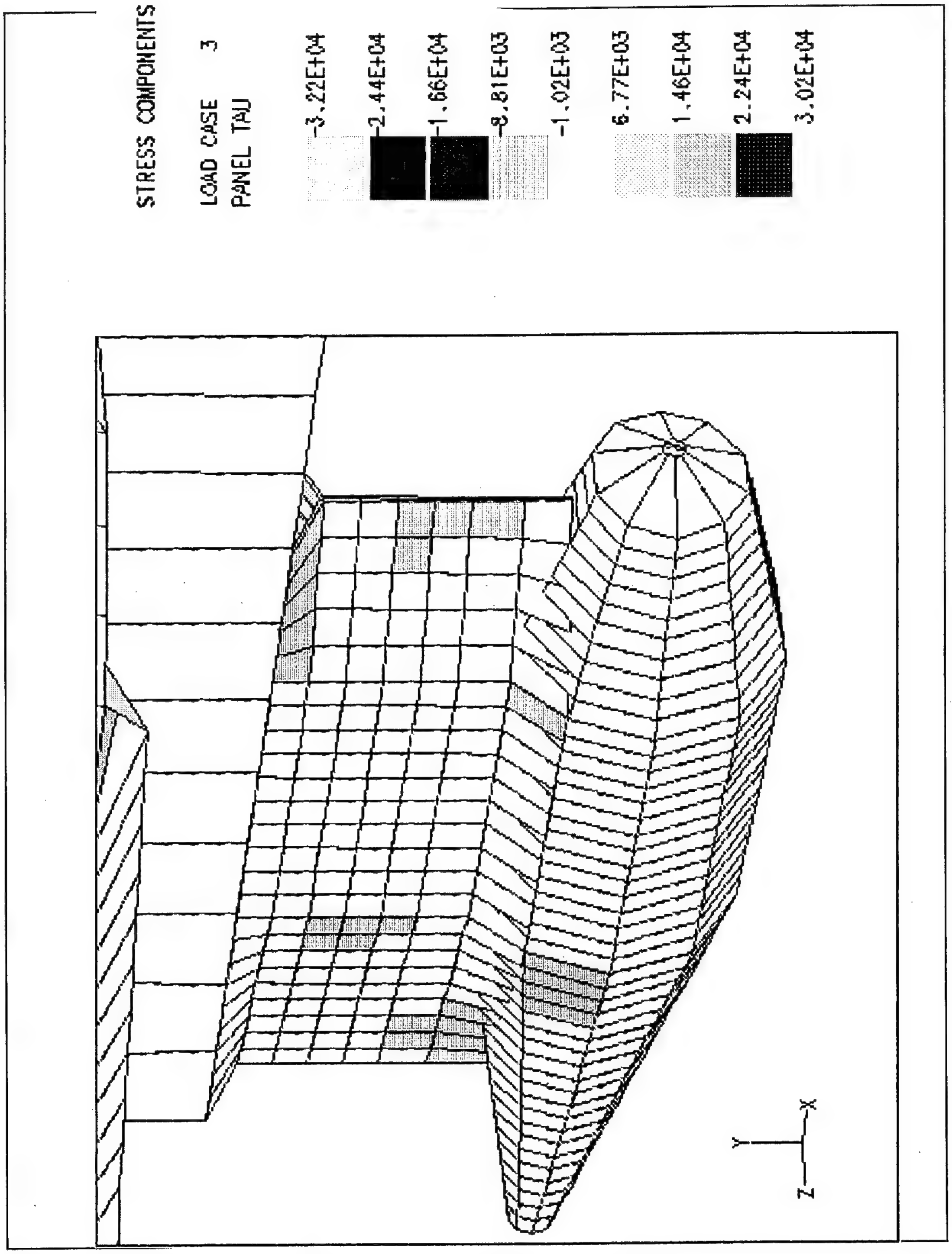

Figure 13. Forward Pod's Shear stress response to case (3).

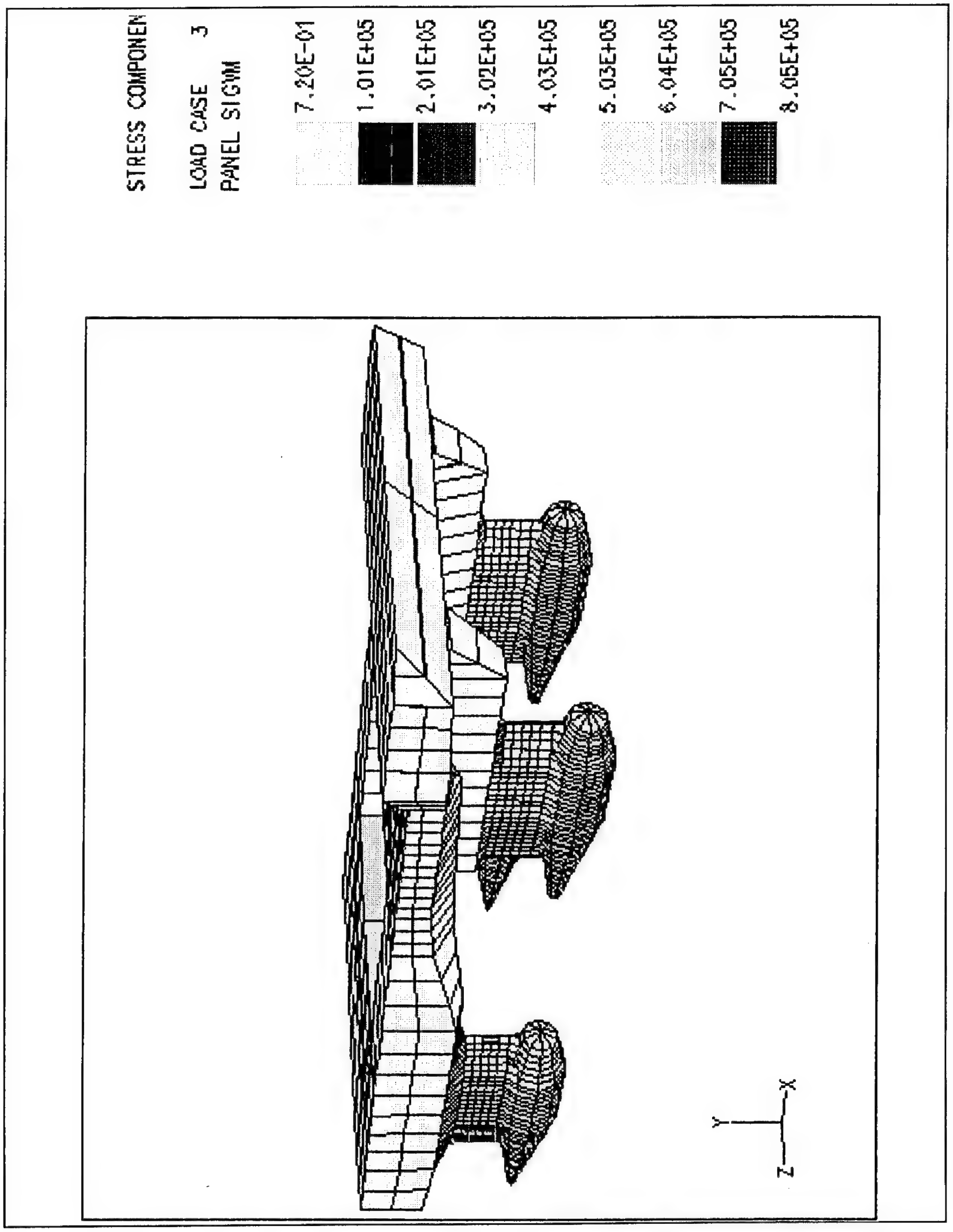

Figure 14. SLICE's Von Mises Stress response to case (3).

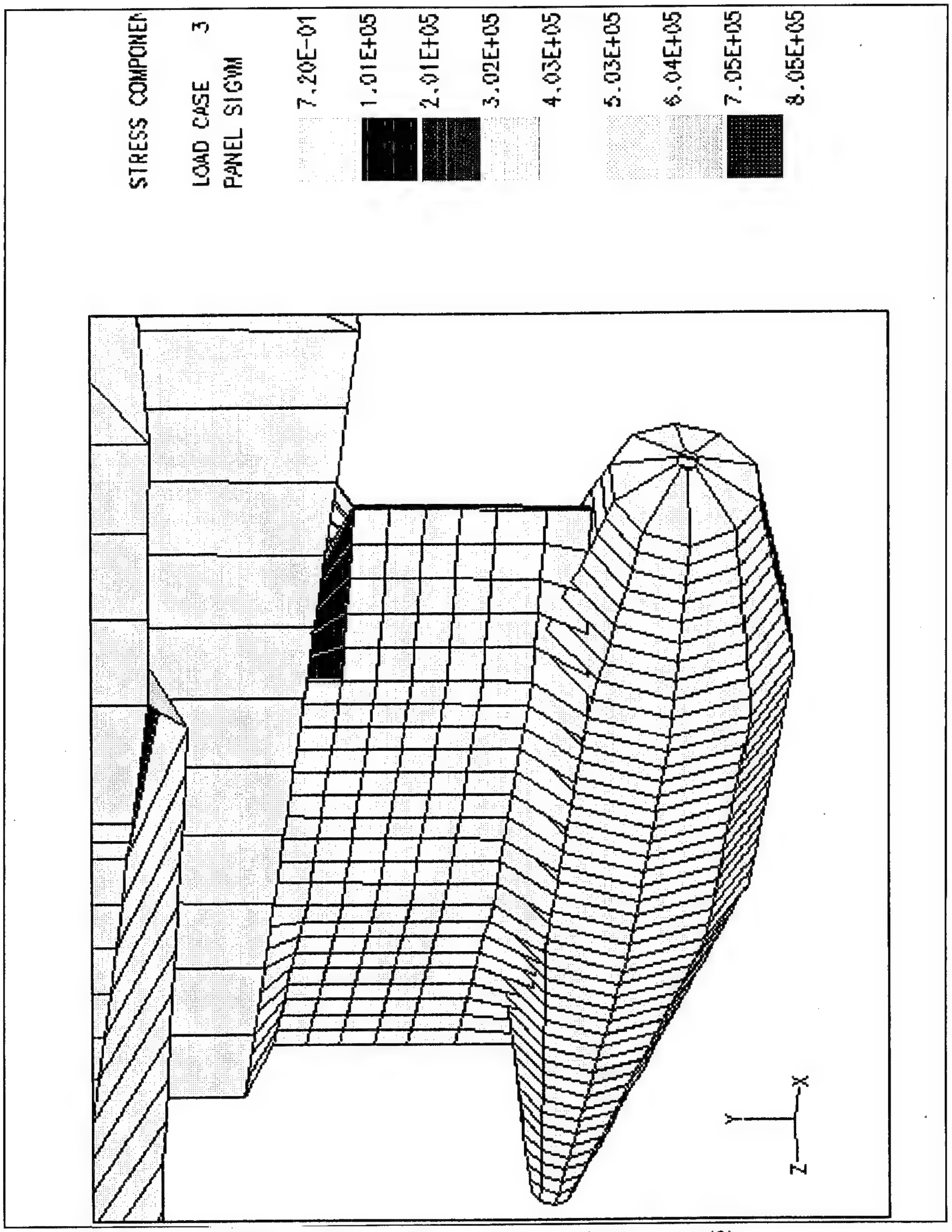

Figure 15. Forward Pod's Von Mises Stress response due to case (3).

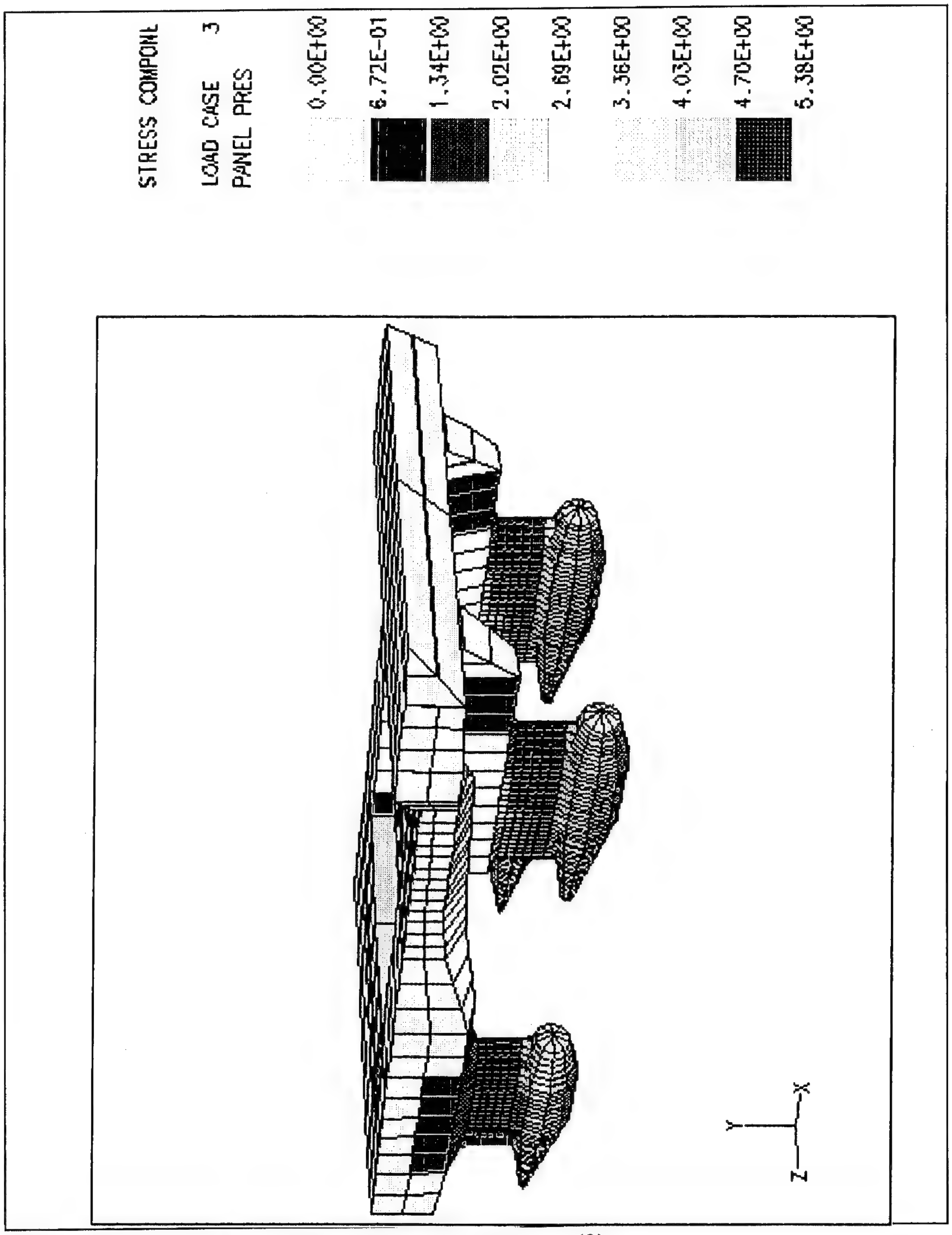

Figure 16. SLICE's Panel Pressure response to case (3).

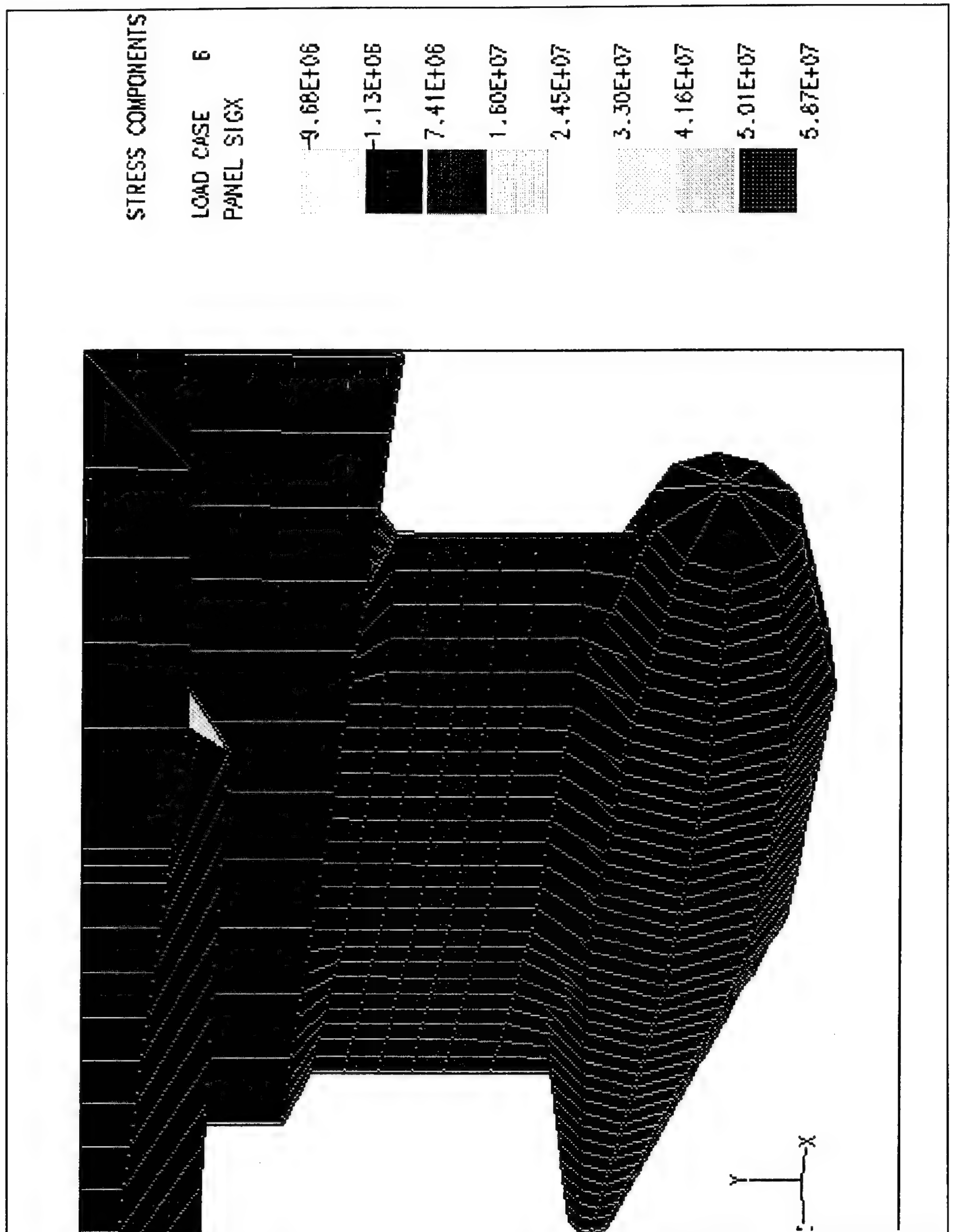

Figure 17. Forward Pod's SigmaX stress response to case (6).

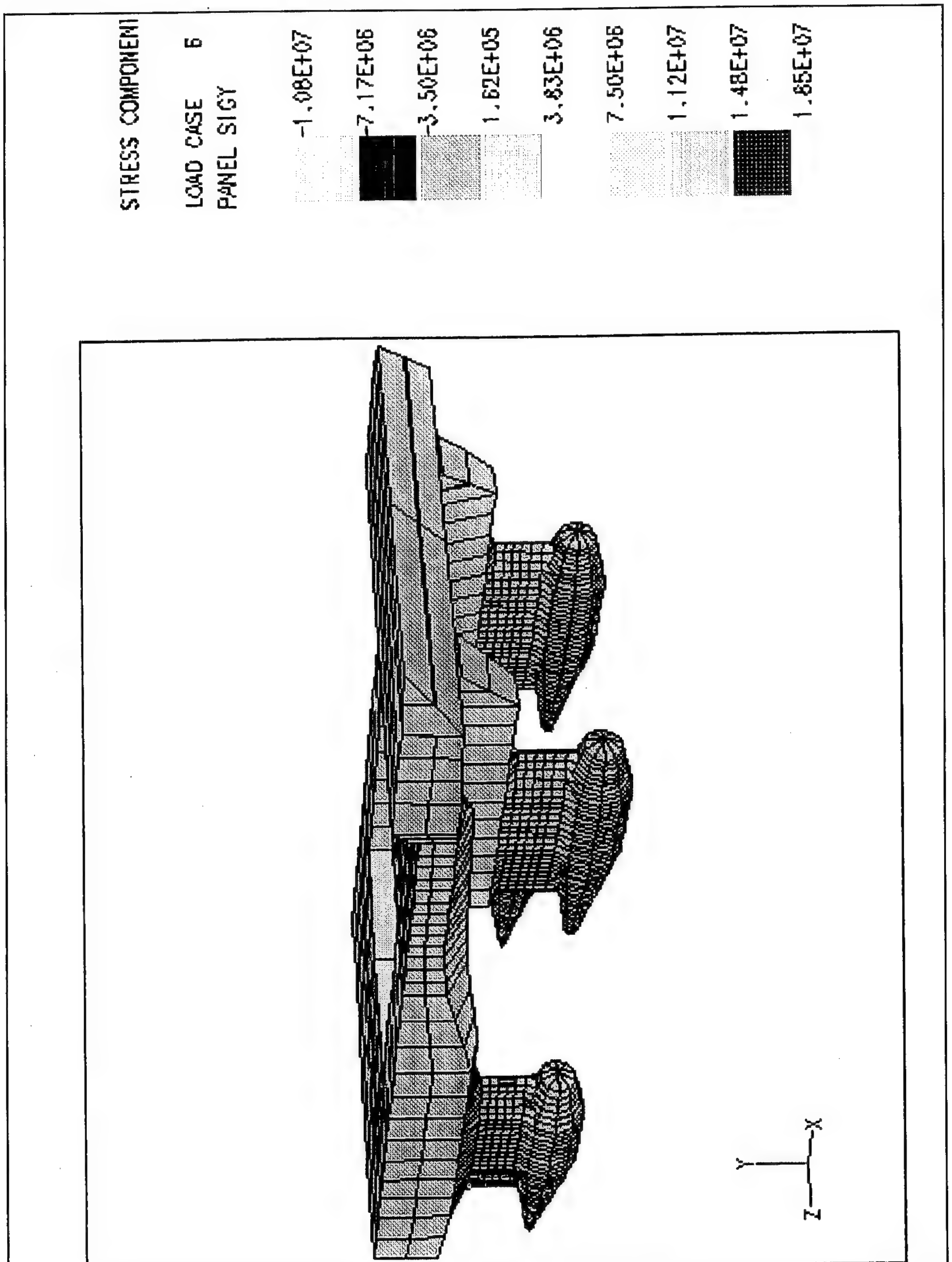

Figure 18. SLICE's SigmaY stress response to case (6).

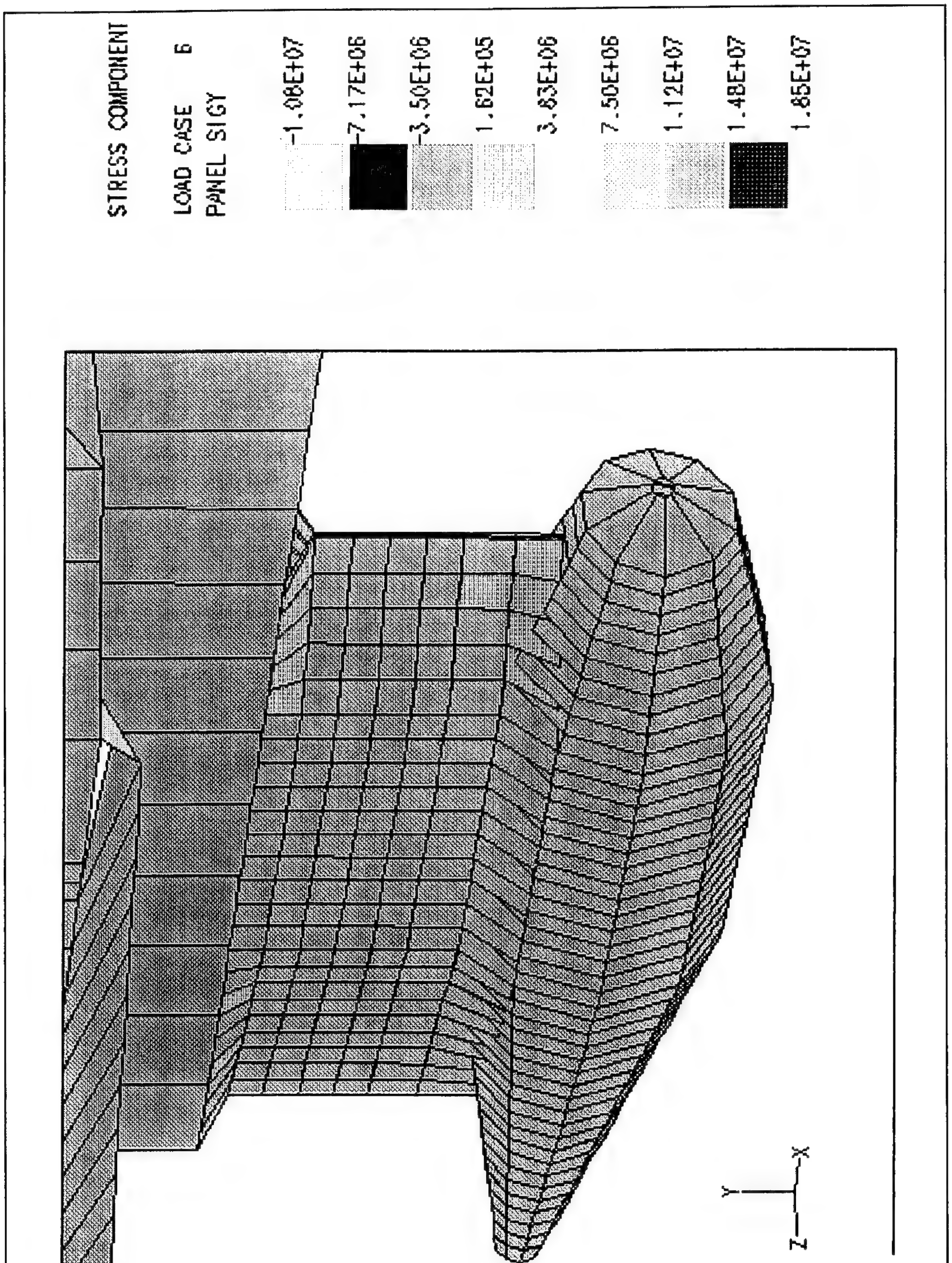

Figure 19. Forward Pod's SigmaY stress response to case (6).

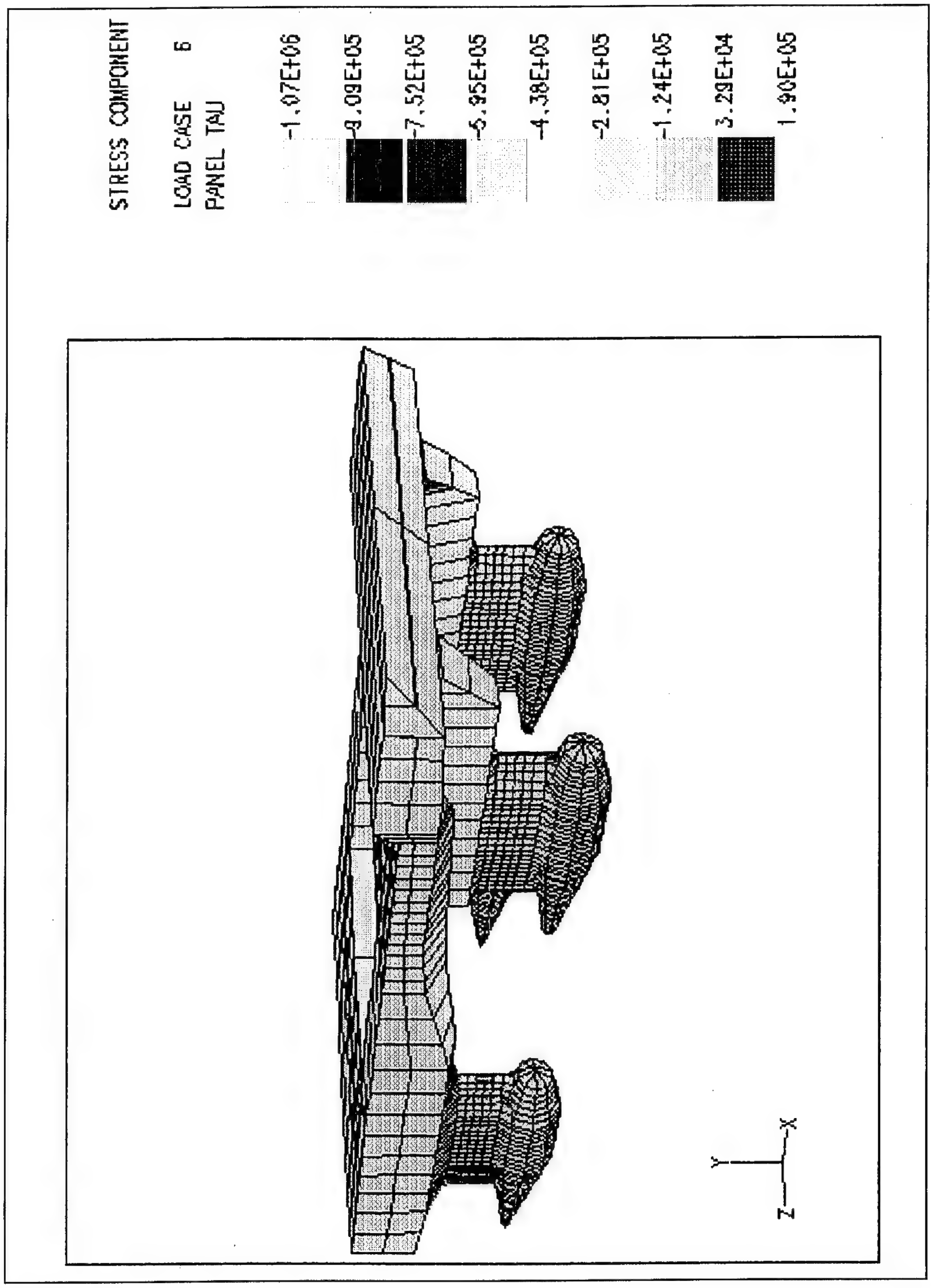

Figure 20. SLICE's Shear stress response to case (6).

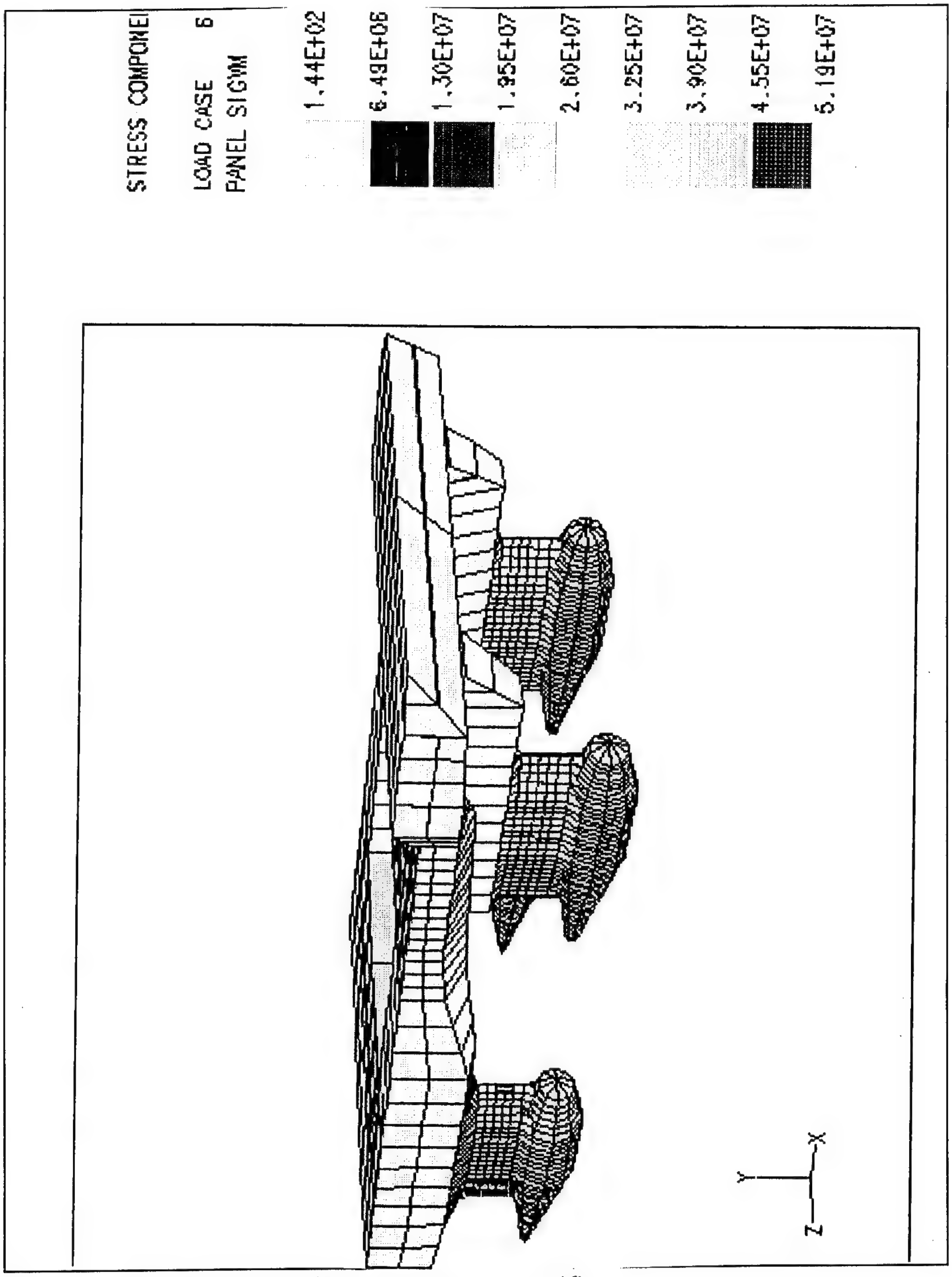

Figure 21. SLICE's Von Mises response to case (6).

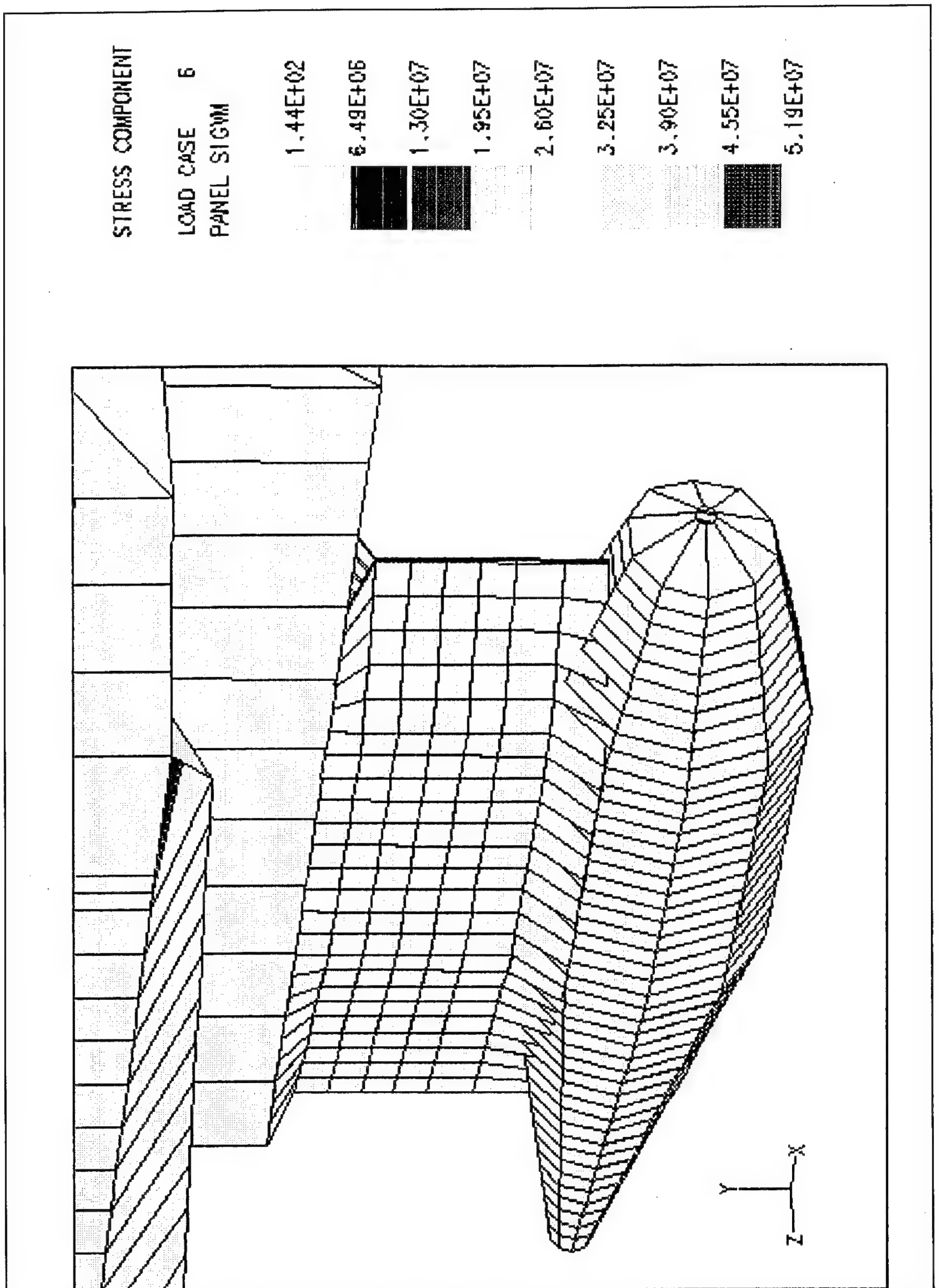

Figure 22. Forward Pod's Von Mises stress response to case (6).

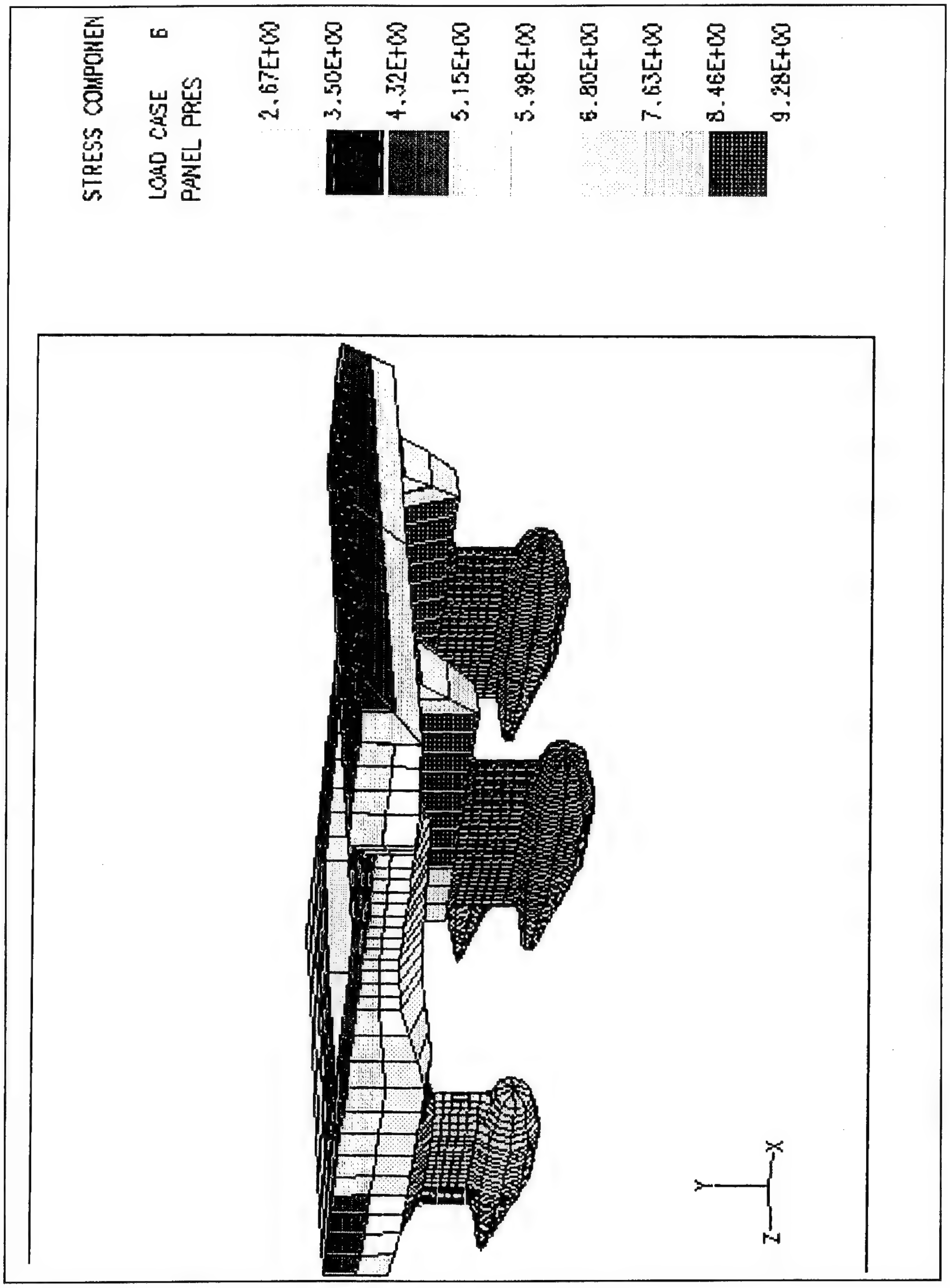

Figure 23. SLICE's Panel Pressure response to case (6).

3. Validate the Results from MAESTRO by Changing the "Box" Stiffener Size and Compare Results to the Baseline Model

To validate the results from MAESTRO, the "adequacy parameters" for two models will be compared. By reducing the stiffener's dimensions, higher stress magnitudes and possibly panel failure is expected in the box. Model 1 (baseline model) has the larger box stiffeners, and model 2 has the smaller box stiffeners. The only stiffener modeled in MAESTRO is the "T" type. Both model's were exposed to the same sea state 8, and same load case (6). As presented earlier, the same breadth to depth ratio was maintained for both models. The stiffener for model 1 (baseline) is as follows: breadth - 3 inches, depth - 6 inches, web - 0.25 inches. For model 2, the stiffener's dimensions are: breadth - 0.25 inches, depth - 0.5 inches, web - 0.2 inches. Figure 24 illustrates the dimensions for both stiffeners.

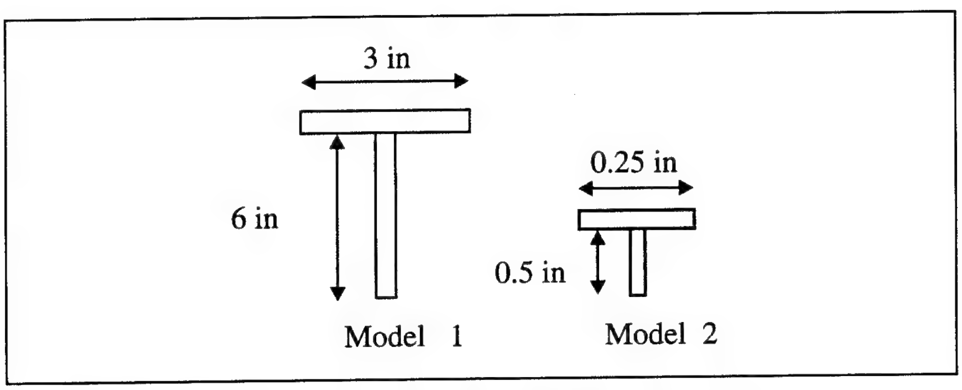

Figure 24. Box Stiffener dimensions for both SLICE models.

The "adequacy parameters" for the panel elements in both models are as follows: transverse plate bending (PSBT), longitudinal plate bending (PSPBL), and local buckling panel failure (PFLB). The following figures will present the above "adequacy parameters" for case (6) which represents the worst case scenario. Figure 25 represents the transverse plate bending for the baseline model which has the larger box stiffeners. Figure 26 illustrates the transverse plate bending for model 2. The box structure in Figure 26 is shown to fail by the (-1) "adequacy parameter". However, the same box structure in Figure 25 has better "adequacy parameter" results. This indicates that in transverse plate bending, the larger stiffeners react better than the smaller stiffeners.

Figures 27 illustrates the longitudinal plate bending "adequacy parameter" for the baseline model. Figure 28 illustrates the same longitudinal plate bending "adequacy parameter" for model 2. Again, Figure 28, which represents model 2 with the smaller stiffeners, shows more box panel failures according to the (-1) "adequacy parameter". This shows that in longitudinal plate bending, again the baseline model is better than model 2. The last "adequacy parameter" presented is the local buckling panel failure. Figure 29 illustrates the local buckling panel failure for model 1, and Figure 30 illustrates the same failure for model 2. Figure 30 has slightly more box panel failures (-1) than Figure 29. However, these figures do not provide a more detailed representation of local buckling panel failure for both models. Model 1, in Figure 29, reacts better due to the larger box stiffeners. Also to further validate MAESTRO, a simple structure was analyzed using classical analytical theory and MAESTRO. Appendix C illustrates the problem and solution. The results from both MAESTRO and analytical solution were similar. As expected, MAESTRO appears to be providing reasonable results, which validates the conclusions of this work.

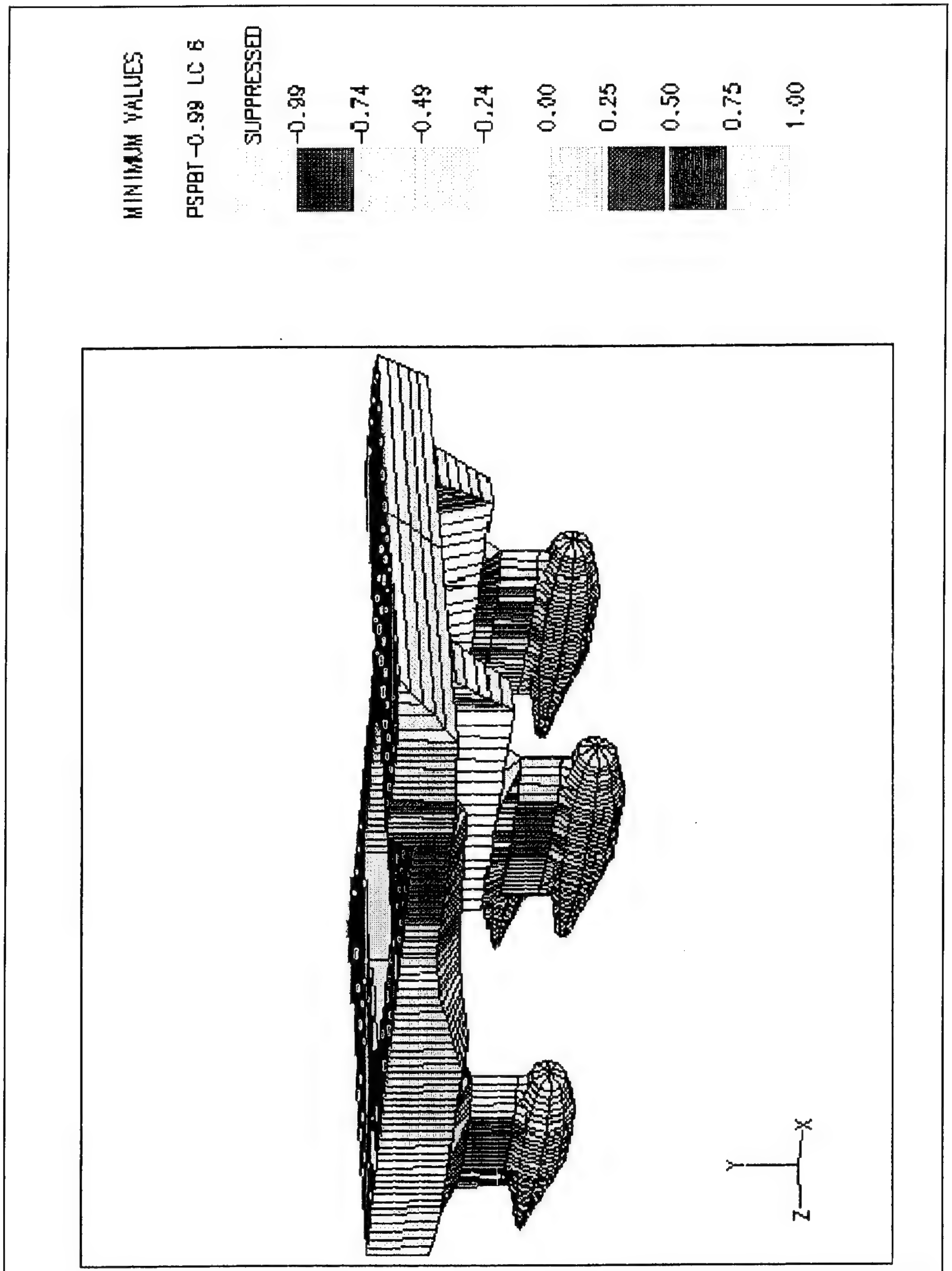

Figure 25. Transverse Plate Bending for Baseline Model.

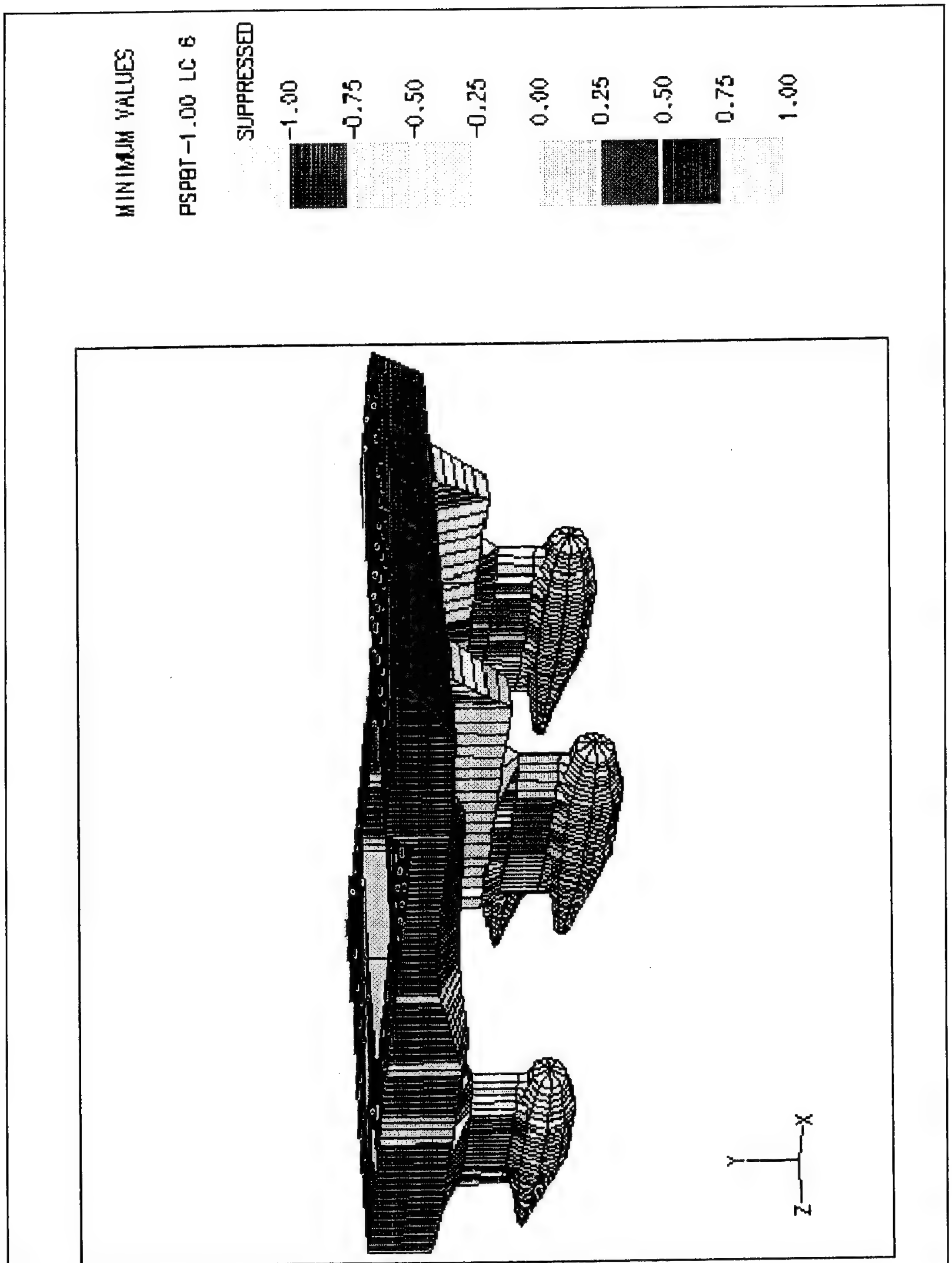

Figure 26. Transverse Plate Bending for Model 2.

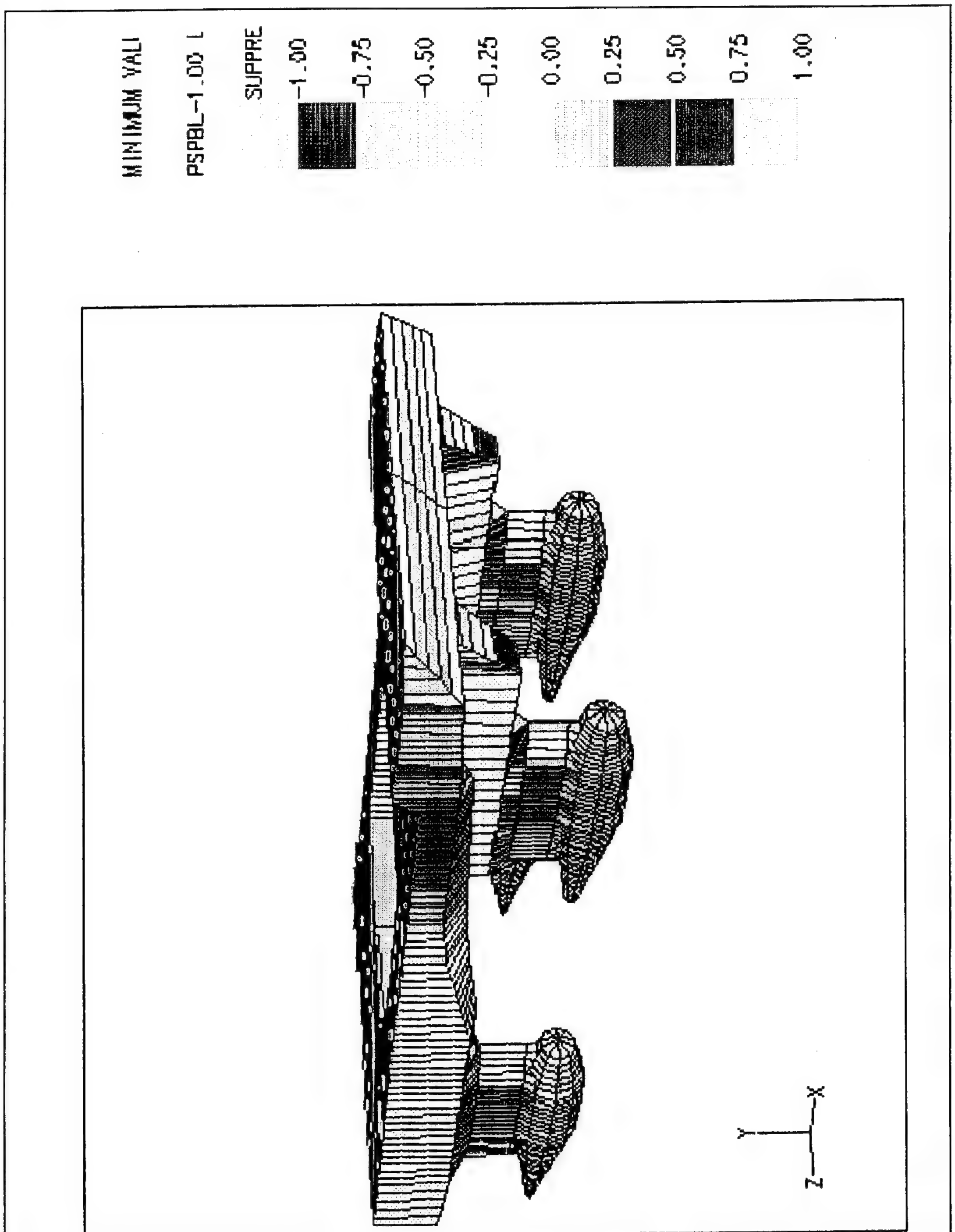

Figure 27. Longitudinal Plate Bending for Model 1.

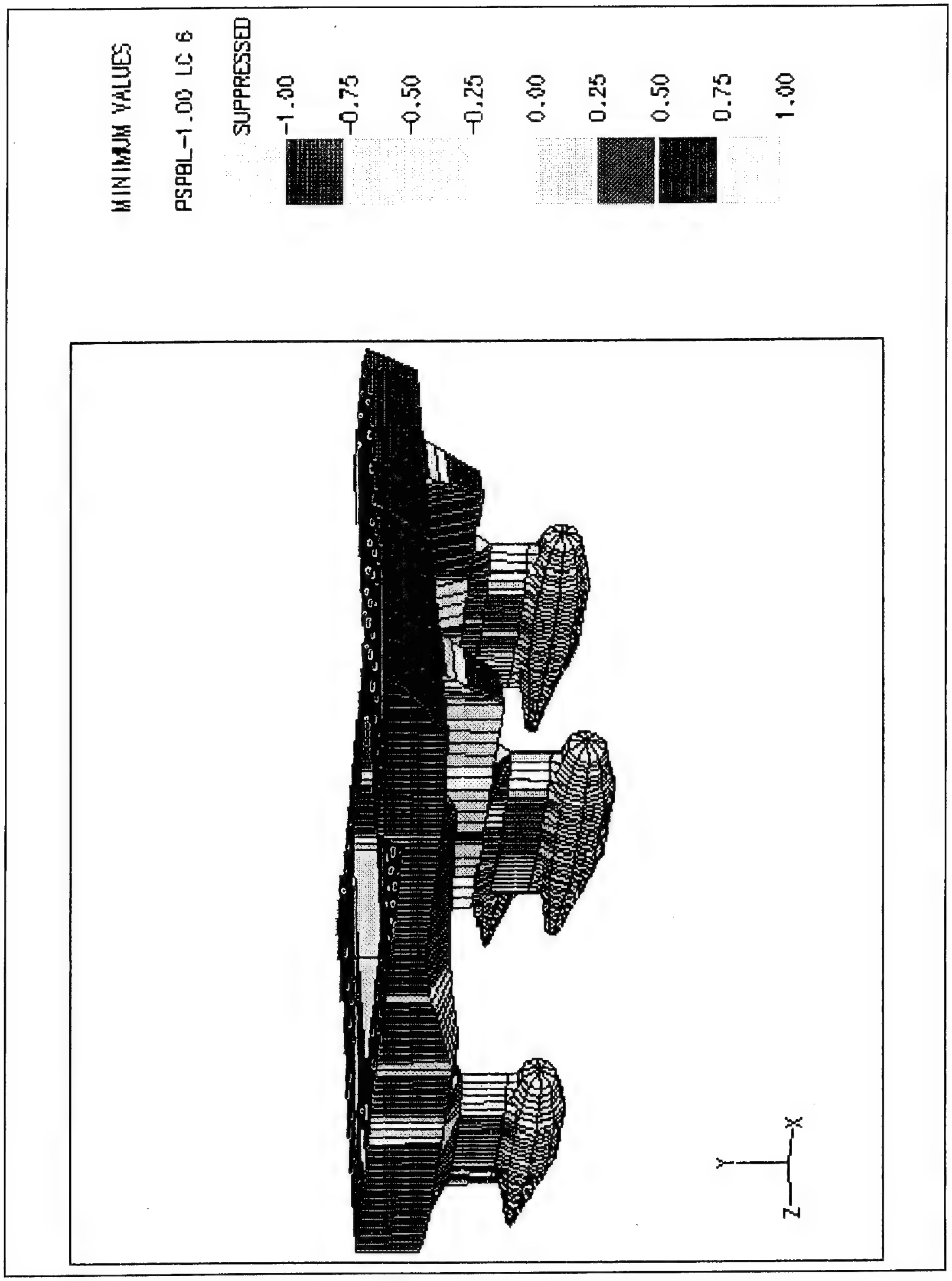

Figure 28. Longitudinal Plate Bending for Model 2.

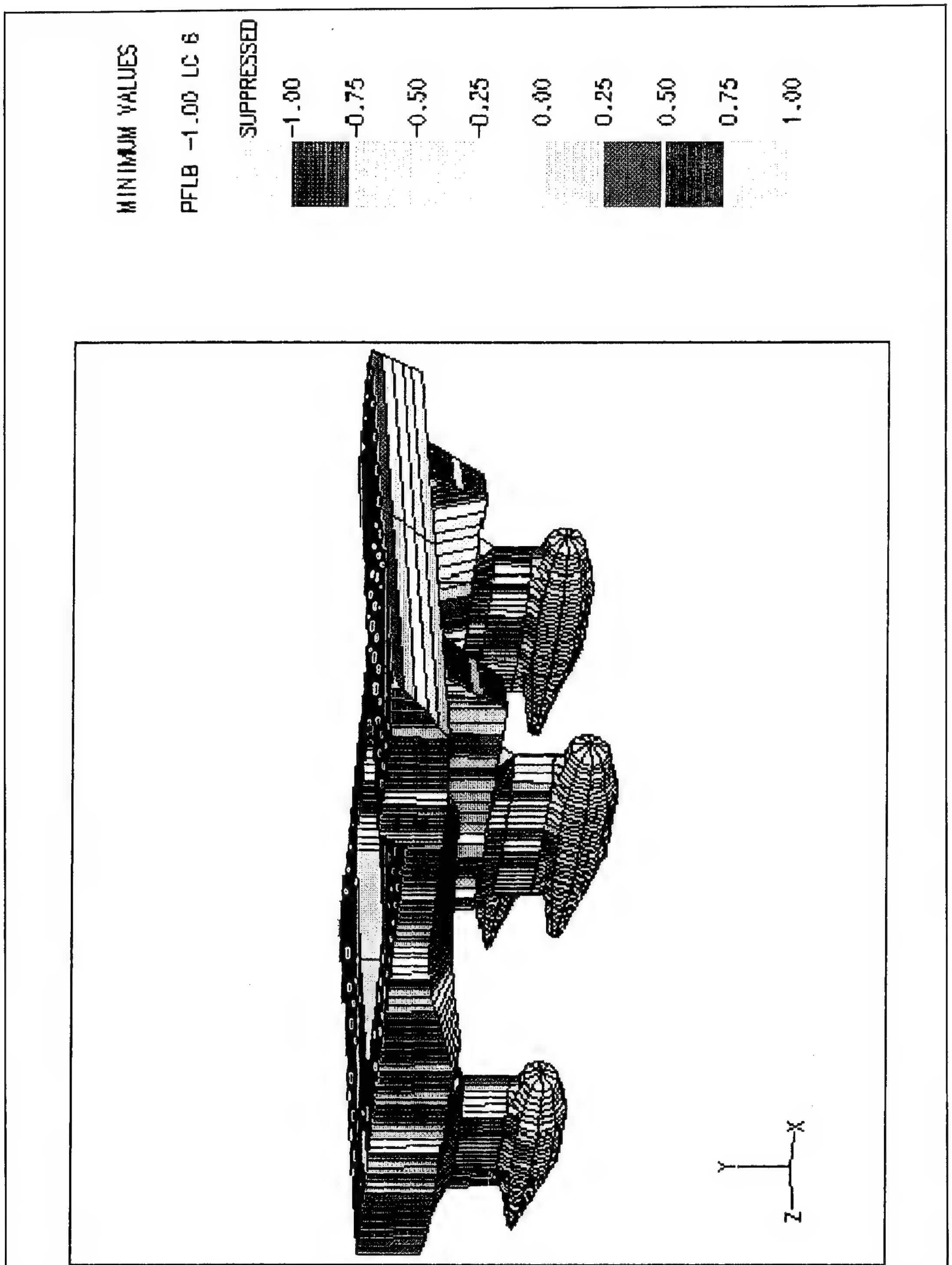

Figure 29. Local Buckling Panel Failure for Model 1.

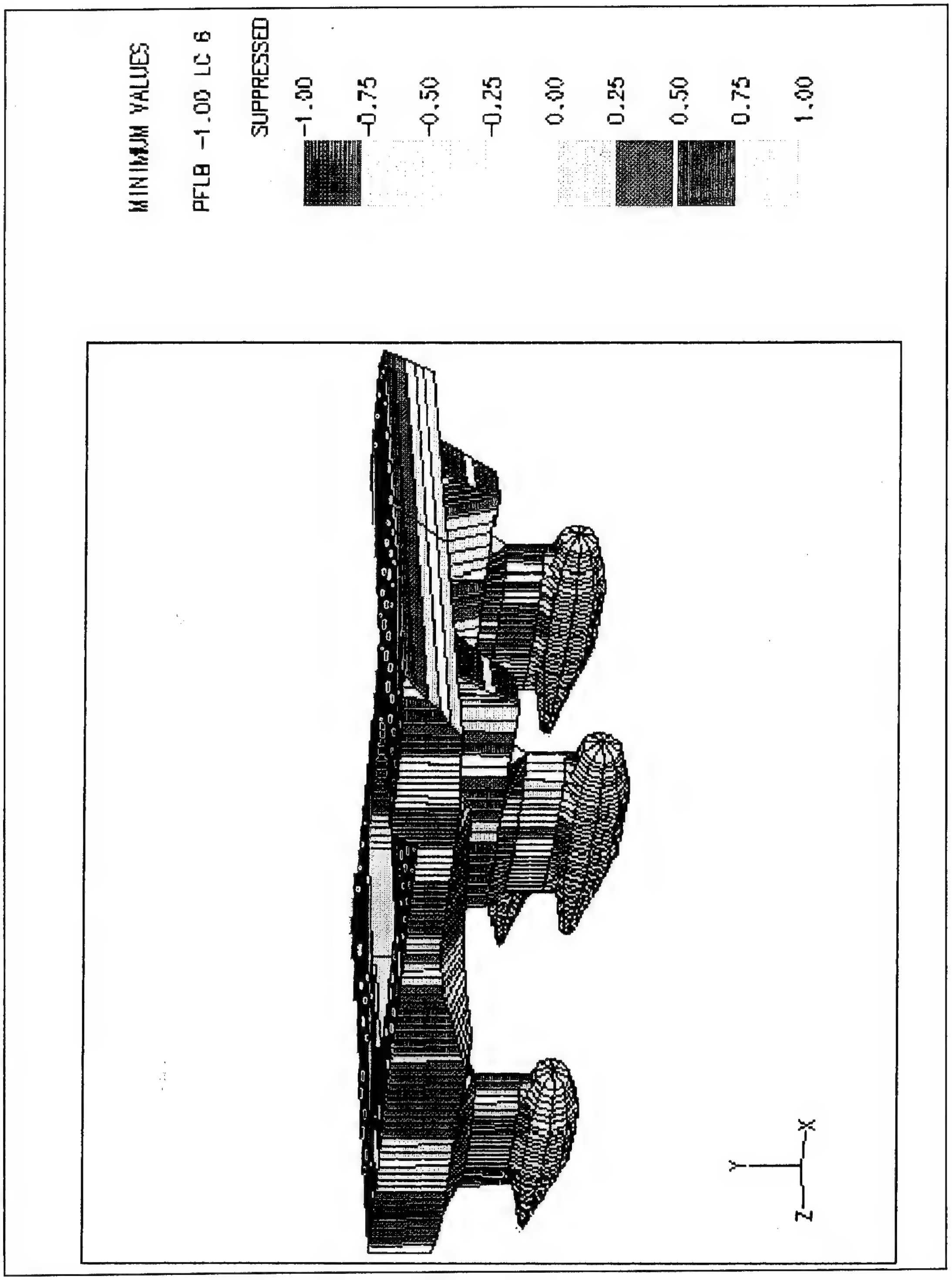

Figure 30. Local Buckling Panel Failure for Model 2.

IV. CONCLUSIONS AND RECOMMENDATIONS

This work examined three main concerns with the transverse structure due to the SLICE's lack of continuous underwater hull. Investigation of the first concern, which dealt with the SLICE structure's reaction to varying sea directions and load cases presented by MAESTRO, showed that the SLICE structure modeled was insensitive to sea directions. The second concern dealt with beam sea/hull interaction. MAESTRO demonstrated that the SLICE reacted like a SWATH to the beam sea/hull interaction. The last concern dealt with the validation of MAESTRO results. A model with small box stiffeners was subjected to the same sea state and load cases to the MAESTRO model. The "adequacy parameters" was used to compare the two models. As expected, the model with the small box stiffeners had higher stress distributions and met more panel failure criteria and this verifies that MAESTRO results appear reasonable.

To further improve on the results provided by MAESTRO, the following recommendations are proposed. First, the model can be changed by making a long continuous underwater hull maintaining the same displacement and exposing to same sea states 5 and 8 and load cases. The results then could be compared to this work. Since MAESTRO works with large finite elements comprising the actual structure, the results are only approximations and a 2-D finite element could be used to provide better results for high stress areas. Third, since this work was conducted with only the initial SLICE drawings which were not very detailed, the model in MAESTRO's input data file could be changed to reflect the latest drawings. Another recommendation is to model the SLICE structure in other finite element programs and compare the results with this work. The biggest advantage of MAESTRO is that the hydrodynamic wave loads are calculated during the MAESTRO run. This data could be helpful for follow on work in other programs such as IDEAS.

In conclusion, the SLICE structure modeled in MAESTRO for this work appears to be satisfactory in design. However, the result are not completely conclusive due to the

limitations imposed from the lack of details from the initial SLICE drawings. Also, this investigation was not able to find the structure's natural frequency due to limitations in MAESTRO.

APPENDIX A. DESCRIPTION OF SLICE INPUT FILE

The following is the description of the SLICE input data file for MAESTRO. The assumption is that the reader is not familiar with the MAESTRO input format. A total of seven substructures and 26 modules are included in the input data file in Appendix B. In addition, two tables will be provided. One table lists the static loads, and the other table lists the substructure/module layout.

A. DESCRIPTION OF FIRST NINE LINES IN MAESTRO INPUT DATA FILE

Every line, blank or with text, in the MAESTRO input data file is significant for a successful run. The first line in the input data file is the job title and must be enclosed in quotation marks. The second line is the job information. Each line is represented by various item numbers. For example in this line the letter "A" represents item one. "A" stands for "ANALYSIS." The second item number is used for the total number of design cycles for this job. The number "2" was used. For an ANALYSIS job, any nonzero number is indicates a normal execution. Item three is a positive number "1" that indicates that the nodal deflections from the finite element analysis are saved. The third line defines the structure parameters. In item one, "2" indicates that all graphics files are to be generated. In item two, "1" indicates the structure only symmetry and the loadcases are not considered symmetrical. In item three, "3" defines the level of detail of the output. In item four, "3" is define the evaluation level for the overall structure. In this case, more detail is provided regarding panel stresses. Item five indicates the station spacing. A comma indicates to the program to ignore the item number. Item eight and item nine allows the user to specify the starting point for a module in the global renumbering. Default is substructure "1" and module "1" as indicated as the last two items. Line four represents the units used for this job. Item one is the word "UNITS" which is required. Item two is the name of the force. Pound was used. Item three is the name of the length (inches). Item four is the name of the cost unit used for optimization phase that was not used in this work. Item five is the name of the weight unit. Pound was chosen. Line five defines the combined safety factors for member collapse. Item one "CRITERIA" is

required. Item two "DEFAULT" was selected for defaults safety factors. Items four and five (1.5 and 1.25) are the safety factors. Line six defines the material type and properties. In item one, the type of material is defined by "AL." Item two is the number of material types which for this model "1" is used. Item three is the Young's Modulus. Item four is Poisson's ratio. Item five is the yield stress for this material. Item six is the ultimate tensile strength. Item seven was ignored. Item eight is the material density. The last items are default values. Line seven is the second type of material and properties. The substructure identifier begins in line eight. Item one is the word "SUBSTRUCTURE." Item two is the identification number of this substructure. Item three and item four are not used. Line nine identifies the structure's origin of axes. Item one is the x values "0." Item two is the y value "0." Item three is the z value "0." Line 10 is the module identifier. The same format follows for all modules in all seven substructures. The endpoints and strake will be presented for the first module.

B. DEFINITION OF DATA GROUPS FOR MODULE 1

1. Module 1

Data group I provides the basic module parameters. The most important item for this line is item 3 which defines the starting point for the module. Group I(a), the next line presents more information. Item 1 provides the number of section intervals in the module. If the module included any cylinder, then item 6 would define the length between bulkheads (circular diaphragms). For this module this item is defined by "0." The next line is group I(b) which is the module default values. Item 1 defines the section spacing.

Data group II which defines the endpoint locations is the next line. One line is needed for each endpoint. Each line in this group contains the module coordinates in the y - - z plane. Table 1 defines the endpoints for this module. After the last endpoint the next line must be an "END" terminator. Data group III was not used.

Endpoint #	Y Value	Z Value	New Y Value	New Z Value
1	0	0	0	0
2	0	312	0	276
3	-73.6	0	-0.5	0
4	-73.6	312	-0.5	276

Table 1. Endpoints for Sub. 1 Mod 1

Group IV(a) is the definition of strakes with one line per strake. Item 1 defines the type of strake. Since module 1 is not near the water line, the type of strake selected is "SIDE." For modules near or below the waterline, strake is defined by "BOTTOM" type. Item 2 is strake number which must be chronological in number. Item 3 is endpoint defining strake edge 1. Item 4 is endpoint defining strake edge 2. Item 5 defines the material type of the strake. Item 6 defines the material type of stiffeners. Item 7 also defines the material type for the frames of this strake. Item 9 defines the strake panel geometry. For this module, "L" for longitudinal was selected. Item 10 indicates curved strake that was not used in this module. Item 11 defines the frame web orientation to respect to the plating. For this module, "XT" indicates that the web orientation is in the transverse plane. Item 12 was not used. Item 13 defines where the transverse frame is placed. In this module, the "-1" indicates that a frame is placed at every section with no skipping. An "END" terminator is required as the last line of this data group. Data group IV(b) defines the longitudinal girders which was not used in this module. The "END" terminator is required in the next line.

Data group V defines the superelement data. This group was not needed for this module. Data group VI identifies the strut and triangle elements again this was not needed. Data group VII defines any additional beams and panels also not used for this

module. Data group VIII is reserved for future program use, again not used in this module.

Data group IX defines the stiffened panel scantlings. For unstiffened panels only the plate thickness is required in item 3. Group X defines the longitudinal girder scantlings. This group was not used for this module. Group XI defines the transverse frame scantlings. The items defines the height of web, web thickness, flange width, and flange thickness. Data group XII(a) defines any additional panel scantlings which was not needed for this module. Data group XIII defines brackets that was not needed but the "END" terminator is required. The next data group is group XV that defines any deletions of elements and nodes. Again this was not required for this module, but the single "END" terminator is required for this data group. Module 2 begins on the next line. The same format identified for module 1 applies to all the modules. The only significant difference was in the type of strake needed for the pods in substructures 4 and 6. The type required for the cylindrical modules is the "LCY" which defines the longitudinal cylindrical "curved" strake. The complete description for the rest of the substructures and modules is contained in Appendix B.

2. Boundary Conditions and Load Definitions

Data group XVIII defines the boundary conditions for this work substructure 1 module 1 defines the lower boundary module and substructure 2 module 4 defines the higher boundary module. The next data group defined is group XVIII(b) which is the centerplane restraint. Data group XVIII(d) identifies the general restraints.

The next data group XIX defines the definition of loadsets. A total of 13 loadsets are provided in Appendix B. The first loadset defined is the static loads. Table 2 illustrates the static loads inputted for this work. The rest of the loadsets define the required wave load data for the varying wave/hull interactions. In each loadset, a series of blank lines is needed to represent every module. Some loadsets have 26 blank lines representing the modules. The blank lines are needed for a successful run. Data group XX is the definition of loadcases. A total of 6 loadcases is defined in Appendix B. The

load terminator "ENDLOADS" signifies the end of the data input file. This terminator is required to end all data input. Table 3 illustrates the complete layout for the SLICE structure. Each module in each substructure is listed. The DATA PREPARATION MANUAL [Ref. 9] provided the necessary details of the contents for Appendix B.

Mod. #	Description	Subst	Module	Section	Length	wt (lton)	wt/2 (lton)	wt pounds	lb sect.
14	**Propulsion plant**	4	2	15	8	28.21	14.105	31,595	263.3
10	**Electric Plant**	2	4	5	16.8	6	3	6,720	56
6	**Auxiliary Systems**	1	6	5	16.8	10	5	11,200	133.3
3	**Outfit and furnishings**	1	3	6	10	6	3	6,720	112
2	**Crew**	1	3	10	12.6	0.14	0.07	156.8	1.244
12	**Fuel Oil**	3	2	1	12.3	8.95	4.475	10,024	76.9
19		5	3	9	12				
20	**Fuel Oil**	6	1	1*	12	8.95	4.475	10,024	29.83
21		6	2	10	12				
9	**Payload**	2	3	11**	18.5454	30	15	33,600	165.2
8		2	2	10	16.8				
6		1	6	1*	16.8				

Table 2. Static weight distribution on the SLICE

	Substructure Number	Module No.	Section	Position of X value (negative)	Length
1	1	1	2	66	33
2	1	2	3	192	42
3	1	3	1	252	60
4	1	4	2	270	9
5	1	5	10	504	23.4
6	1	6	3	588	28
7	2	1	3	768	60
8	2	2	3	936	56
9	2	3	4	1140	51
10	2	4	2	1260	60
11	3	1	2	138	27
12	3	2	11	540	36.54
13	4	1	20	624	9.6
14	4	2	15	432	8
15	4	3	10	312	7.2
16	4	4	1	240	12
17	5	1	5	312	12
18	5	2	10	432	12
19	5	3	9	540	12
20	6	1	18	1260	12
21	6	2	10	1044	12
22	6	3	6	924	12
23	6	4	1	852	12
24	7	1	6	924	12
25	7	2	10	1044	12
26	7	3	8	1140	12

Table 3. Substructure/Module SLICE Layout

APPENDIX B. DATA FILE INPUT FOR SLICE STRUCTURE

The following is the code of the input data file used in this thesis. Appendix A described some of the details of this input. Again as a reminder, blank spaces within the code are necessary for the program and their placements are intentional. The complete description for this file can be found in the MAESTRO DATA PREPARATION MANUAL [Ref. 9].

```
"LATEST SLICE.DAT - SLICE;"
A 2 1
2 1 0 3 12 , , 1 1 , , , , ,
UNITS POUNDS INCHES K-DOLLARS POUNDS
CRITERIA DEFAULT 1.50 1.25
AL 1 10.3E+06 0.3 24E+03 39E+03 , 1 0.096 .10 1.
AL 2 10.3E+06 0.3 42E+05 78E+05 , 1 0.096 .10 1.
SUBSTRUCTURE 1 0 0
0. 0. 0.
MODULE 1 -66. 0. 0.    $ DATA GROUP I
1 0 , 0 0 0 0 1 N N 1 $ DATA GROUP I(B)
66 , , 1.0 0 1.0
0.    0.               $ DATA GROUP II
0.    312.   0.  276.
-73.6  0.    -.5  0.
-73.6  312.  -.5  276.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1      $ DATA GROUP IV(A)
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 4 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L , XT , -1
END
END                                 $ DATA GROUP IV(B)
ENDSUP                                  $ DATA GROUP V
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 2 1 1 1
1 1 .25 2 1 1 1
1 1 .25 2 1 1 1
1 1 .25 2 1 1 1
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
2 1 1 1
2 1 1 1
2 1 1 1
2 1 1 1
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
```

```
END                                                      $ DATA GROUP XIII
$GROUP XV - DELETIONS
END
MODULE 2  -192.  0.  0.
3 0 , 0 0 0 0 1 N N 1
42 , , 1.0 0 1.0
0.   0.
0.   312.
-84   0    -73.6  0
-84   312  -73.6  312
-84.  156.
-84.  204.
-42.  312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 7 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 7 4 1 1 1 0 L , XT , -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 3  -252.  0.  0.
1 0 , 0 0 0 0 1 N N 1
60. , , 1.0 0 1.0
0.   0.
0.   312.
-84.  0.
-84.  312.
-84.  204.
-87.  258.   -84.   258.
-84.  156.
-84.  204.
-42.  312.
```

```
END
SIDE 1 1 2 1 1 1 0 L ,XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 9 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 5 6 1 1 1 0 L
SIDE 6 6 4 1 1 1 0 L
SIDE 7 9 4 1 1 1 0 L , XT , -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 4 -270. 0. 0.
2 0 , 0 0 0 0 1 Y N 1
9. , , 1.0 0 1.0
-24. 0. 0. 0.
-24. 312. 0. 312.
-84. 0.
-84. 312.
-84. 204.
-108. 258. -87. 258.
-84. 156.
-84. 204.
-54. 312. -42. 312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 9 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 5 6 1 1 1 0 L
SIDE 6 6 4 1 1 1 0 L , -XT , -1
```

```
SIDE 7 9 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 1 3 4 2 1 .25
ELEM 2 5 6 4 0 1 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 5 -504. 0. 0.
10 0 , 0 0 0 0 1 N N 1
23.4 , , 1.0 0 1.0
-36. 0.
-36. 312.
-84. 0.
-84. 312.
-84. 204.
-120. 258. -108. 258.
-36. 156.
-36. 204.
-60. 180.
-84. 156.
-60. 312. -54. 312.
END
SIDE 1 1 8 1 1 1 0 L , XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 11 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 5 6 1 1 1 0 L
```

```
SIDE 6 6 4 1 1 1 0 L ,-XT , -1
SIDE 7 7 10 1 1 1 0 L , -XT , -1
SIDE 8 8 5 1 1 1 0 L
SIDE 9 7 8 1 1 1 0 L , XT , -1
SIDE 10 8 2 1 1 1 0 L , XT , -1
SIDE 11 11 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0.975610
END
ELEM 1 1 3 10 7 1 .25
+ 2 10 5 8 7 1 .5
+ 3 5 4 2 8 1 .5
+ 4 5 6 4 0 1 .5
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 6 -588. 0. 0.
3 0 , 0 0 0 0 1 Y N 1
28 , , 1.0 0 1.0
-36. 0.
-36. 312.
```

```
-96.  0.    -84.   0.
-96.  312.  -84.   312.
-96.  204.  -84.   204.
-126. 258.  -120.  258.
-66.  312.  -60.   312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 7 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 5 6 1 1 1 0 L
SIDE 6 6 4 1 1 1 0 L , -XT , -1
SIDE 7 7 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 1 3 4 2 1 .5
+    2 5 6 4 0 1 .5
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
AUTOJOIN 2 1
AUTOJOIN 3 2
AUTOJOIN 4 3
AUTOJOIN 5 4
+      6 5
END
SUBSTRUCTURE 2 0 0
0. 0. 0.
```

```
MODULE 1 -768. 0. 0.
3 0 ,0 0 0 0 1 N N 1
60 , , 1. 0 1.
-36.  204.
-36.  312.
-144.  204.  -96.  204.
-144.  312.  -96.  312.
-156.  258.  -126. 258.
-90.  312.  -66.  312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 1 3 1 1 1 0 L
SIDE 3 2 6 1 1 1 0 L , XT , -1
SIDE 4 3 5 1 1 1 0 L
SIDE 5 5 4 1 1 1 0 L , -XT , -1
SIDE 6 6 4 1 1 1 0 L , XT , -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(A) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2 -936. 0. 0.
3 0 ,0 0 0 0 1 Y N 1
56 , , 1. 0 1.
-36.  204.
-36.  312.
-144.  204.
-144.  312.
-156.  258.
-90   258.
-90.  312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 1 3 1 1 1 0 L
```

```
SIDE 3 2 7 1 1 1 0 L , XT , -1
SIDE 4 3 5 1 1 1 0 L
SIDE 5 5 4 1 1 1 0 L  , -XT , -1
SIDE 6 7 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 3 5 4 0 1 .5
+   2 3 4 2 1 1 .5
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(A) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 3 -1140. 0. 0.
4 0 , 0 0 0 0 1 N Y 1
51 , , 1.0 0 1.0
-36.  0.
-36.  312.
-144.  0.
-144.  312.
-144.  204.
-156.  258.
-36.  204.
-90.  258.
-90.  312.
END
SIDE 1 1 2 1 1 1 0 L , XT , -1
SIDE 2 3 4 1 1 1 0 L
SIDE 3 2 9 1 1 1 0 L , XT , -1
SIDE 4 1 3 1 1 1 0 L
SIDE 5 5 6 1 1 1 0 L
SIDE 6 6 4 1 1 1 0 L , -XT , -1
```

```
SIDE 7 7 5 1 1 1 0 L
SIDE 8 9 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0 4
END
ELEM 1 1 3 5 7 1 .25
+   2 5 6 4 0 1 .5
+   3 5 4 2 7 1 .5
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 4 -1260. 0. 0.
2 0 , 0 0 0 0 1 Y N 1
60 , , 1.0 0 1.0
-36.  0.
-36.  312.
-136.  0.   -144.  0.
-136.  312. -144.  312.
-136.  204. -144.  204.
-140.  258. -156.  258.
-36   204.
-86.  312. -90.  312.
END
SIDE 1 1 7 1 1 1 0 L , XT , -1
SIDE 2 3 5 1 1 1 0 L
SIDE 3 2 8 1 1 1 0 L, XT , -1
SIDE 4 1 3 1 1 1 0 L
```

```
SIDE 5 5 6 1 1 1 0 L
SIDE 6 6 4 1 1 1 0 L , -XT , -1
SIDE 7 7 2 1 1 1 0 L , XT , -1
SIDE 8 8 4 1 1 1 0 L , XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 1 3 5 7 1 .25
+   2 7 5 4 2 1 .25
+   3 5 6 4 0 1 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
$GROUP XVI - JOINING OF MODULES
AUTOJOIN 2 1
AUTOJOIN 3 2
AUTOJOIN 4 3
END
SUBSTRUCTURE 3 0 0
0. 0. 0.
MODULE 1 -138. 0. 0.
2 0 , 0 0 1 0 1 N Y 1
27   , , 1.0 0 1.0
-156 156 -80 135
-156 204 -80 204
-84 204 -76 204
-84 135 -76 135
```

```
END
SIDE   1 1 2 1 1 1 0 L , -XT , -1
SIDE   2 2 3 1 1 1 0 L ,
SIDE   3 1 4 1 1 1 0 L , -XT , -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
.4375 .25 .5 .15
.4375 .25 .5 .15
.4375 .25 .5 .15
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2 -540. 0. 0.
11 0 , 0 0 1 0 1 Y N 1
36.54 , , 1.0 0 1.0
-84 135
-156 156 -156 156
-156 204 -156 204
-84 204
END
SIDE   1 1 2 1 1 1 0 L , -XT , -1
SIDE   2 2 3 1 1 1 0 L , -XT , -1
SIDE   3 3 4 1 1 1 0 L , -XT , -1
SIDE   4 1 4 1 1 1 0 L , -XT , -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 2 3 4 1 1 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
1 1 .25 6 2 3 2
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
6 2 3 2
6 2 3 2
6 2 3 2
```

```
6 2 3 2
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
AUTOJOIN 1 2
END
SUBSTRUCTURE 4 0 0
0. 0. 0.
MODULE 1 -624. 0 0
20 0 , 0 0 1 0 1 Y N 1
9.6 , , 1.0 0 1.0
-270.59 182.682 -232.9 195.2
-270.59 177.695 -232.9 165.6
-273.36 173.747 -249.6 141.3
-278.278 172.224 -278.1 132.2
-282.918 173.747 -306.7 141.3
-285.827 177.765 -324 165.6
-285.689 182.751 -324 195
-283.057 186.422 -306.7 218.9
-278.278 188.085 -278.1 228
-273.36 186.561 -250.4 218.9
END
BOTTOM 1 1 2 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 2 2 3 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 3 3 4 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 4 4 5 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 5 5 6 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 6 6 7 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 7 7 8 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 8 8 9 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 9 9 10 2 2 2 0 LCY H96 -XT H16 -1
BOTTOM 10 10 1 2 2 2 0 LCY H96 -XT H16 -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM 1 2 3 10 1 2 .25
+ 2 3 4 9 10 2 .25
+ 3 4 5 8 9 2 .25
+ 4 5 6 7 8 2 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
```

```
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2  -432  0  0
15 0 , 0 0 1 0 1 N N 1
8. , , 1.0 0 1.0
-232.9   195.2
-232.9   165.6
-249.6   141.3
-278.1   132.2
-306.7   141.3
-324     165.6
-324     195
-306.7   218.9
-278.1   228
-250.4   218.9
END
BOTTOM  1  1  2  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  2  2  3  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  3  3  4  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  4  4  5  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  5  5  6  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  6  6  7  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  7  7  8  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  8  8  9  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  9  9  10  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM 10  10  1  2  2  2  0  LCY H96 -XT H96 -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
```

```
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - MODIFICATIONS TO THE STRUCTURAL MODEL
TITLE    "OPENING FOR UPTAKES AND ENTRANCE"
PANEL  1  15  THRU  0
FRAME  1  15  THRU  0
END
MODULE 3  -312  0  0
10  0 ,  0  0  1  0  1  N  N  1
7.2  ,  ,  1.0  0  1.0
-232.9    195.2    -253.924  187.984
-232.9    165.6    -253.924  171.405
-249.6    141.3    -262.503  159.149
-278.1    132.2    -278.028  154.655
-306.7    141.3    -293.143  158.74
-324      165.6    -303.357  172.222
-324      195      -303.357  188.155
-306.7    218.9    -294.369  200
-278.1    228      -278.028  206.539
-250.4    218.9    -262.503  201.178
END
BOTTOM  1  1  2  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  2  2  3  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  3  3  4  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  4  4  5  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  5  5  6  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  6  6  7  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  7  7  8  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  8  8  9  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  9  9  10  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM 10  10  1  2  2  2  0  LCY H96 -XT H52 -1
END
END
```

```
SUPER  1  "TRANSVERSE BULKHEAD"
SECTION 5.83333
END
ELEM  1  2  3  10  1   2  .25
+    2  3  4  9   10  2  .25
+    3  4  5  8   9   2  .25
+    4  5  6  7   8   2  .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 4  -240  0  0
1  0  ,  0  0  1  0  1  N  N  1
12.  ,  ,  1.0  0  1.0
-253.924  187.984    -274.511    181.428
-253.924  171.405    -274.511    178.866
-262.503  159.149    -275.886    176.986
-278.028  154.655    -278.18     176.161
-293.143  158.74     -280.539    177.021
-303.357  172.222    -281.914    178.93
-303.357  188.155    -281.504    181.287
-294.369  200        -280.504    183.297
-278.028  206.539    -278.18     184.037
-262.503  201.178    -275.886    183.332
END
BOTTOM  1  1  2  2  2  2  0  LCY H52 -XT H8 -1
```

```
BOTTOM 2 2 3 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 3 3 4 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 4 4 5 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 5 5 6 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 6 6 7 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 7 7 8 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 8 8 9 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 9 9 10 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 10 10 1 2 2 2 0 LCY H52 -XT H8 -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
JOIN 2 7 0 1 7 20
AUTOJOIN 2 1
AUTOJOIN 3 2
AUTOJOIN 4 3
END
SUBSTRUCTURE 5
0. 0. 0.
MODULE 1 -312. 0. 0.
5 0 , 0 0 1 0 1 N Y 1
12 , , 1.0 0 1.0
-156 204
-168 204 -168 181
```

```
-180    204    -180    181
-192    204    -192    181
-204    204    -204    181
-216    204    -216    181
-232.9  204    -232.9  181
-250.4  218.9  -248    181
-249.6  141.3  -248    179
-232.9  156    -232.9  179
-216    156    -216    179
-204    156    -204    179
-192    156    -192    179
-180    156    -180    179
-168    156    -168    179
-156    156
END
BOTTOM  1 1 2 1 1 1 0 L, XT
BOTTOM  2 2 3 1 1 1 0 L, XT
BOTTOM  3 3 4 1 1 1 0 L ,XT
BOTTOM  4 4 5 1 1 1 0 L ,XT
BOTTOM  5 5 6 1 1 1 0 L ,XT
BOTTOM  6 6 7 1 1 1 0 L ,XT
BOTTOM  7 7 8 1 1 1 0 L ,XT
BOTTOM  8 8 9 1 1 1 0 T ,XT
BOTTOM  9 9 10 1 1 1 0 L,XT
BOTTOM  10 10 11 1 1 1 0 L,XT
BOTTOM  11 11 12 1 1 1 0 L,XT
BOTTOM  12 12 13 1 1 1 0 L,XT
BOTTOM  13 13 14 1 1 1 0 L,XT
BOTTOM  14 14 15 1 1 1 0 L,XT
BOTTOM  15 15 16 1 1 1 0 L,XT
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
```

```
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2 -432. 0. 0.
10 0 , 0 0 1 0 1 N N 1
12 , , 1.0 0 1.0
-156    204
-168    204
-180    204
-192    204
-204    204
-216    204
-232.9  204
-250.4  218.9
-249.6  141.3
-232.9  156
-216    156
-204    156
-192    156
-180    156
-168    156
-156    156
END
BOTTOM   1 1 2 1 1 1 0 L, XT
BOTTOM   2 2 3 1 1 1 0 L, XT
BOTTOM   3 3 4 1 1 1 0 L ,XT
BOTTOM   4 4 5 1 1 1 0 L ,XT
BOTTOM   5 5 6 1 1 1 0 L ,XT
BOTTOM   6 6 7 1 1 1 0 L ,XT
BOTTOM   7 7 8 1 1 1 0 L ,XT
BOTTOM   8 8 9 1 1 1 0 T ,XT
BOTTOM   9 9 10 1 1 1 0 L ,XT
BOTTOM   10 10 11 1 1 1 0 L ,XT
BOTTOM   11 11 12 1 1 1 0 L ,XT
BOTTOM   12 12 13 1 1 1 0 L ,XT
BOTTOM   13 13 14 1 1 1 0 L ,XT
```

```
BOTTOM   14 14 15 1 1 1 0 L , XT
BOTTOM   15 15 16 1 1 1 0 L , XT
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - MODIFICATIONS TO THE STRUCTURAL MODEL
PANEL  4  10 THRU 0
FRAME  4  10 THRU 0
END
MODULE 3  -540.  0.   0.
9 0 , 0 0 1 0 1 Y N 1
12 , , 1.0 0 1.0
-156   204
-168   181   -168    204
-180   181   -180    204
-192   181   -192    204
```

```
-204   181   -204    204
-216   181   -216    204
-232.9 181   -232.9  204
-255   181   -250.4  218.9
-255   179   -249.6  141.3
-232.9 179   -232.9  156
-216   179   -216    156
-204   179   -204    156
-192   179   -192    156
-168   179   -168    156
-180   179   -180    156
-156   156
END
BOTTOM  1 1 2 1 1 1 0 L, XT
BOTTOM  2 2 3 1 1 1 0 L, XT
BOTTOM  3 3 4 1 1 1 0 L ,XT
BOTTOM  4 4 5 1 1 1 0 L ,XT
BOTTOM  5 5 6 1 1 1 0 L ,XT
BOTTOM  6 6 7 1 1 1 0 L ,XT
BOTTOM  7 7 8 1 1 1 0 L ,XT
BOTTOM  8 8 9 1 1 1 0 T ,XT
BOTTOM  9 9 10 1 1 1 0 L ,XT
BOTTOM  10 10 11 1 1 1 0 L ,XT
BOTTOM  11 11 12 1 1 1 0 L ,XT
BOTTOM  12 12 13 1 1 1 0 L ,XT
BOTTOM  13 13 14 1 1 1 0 L ,XT
BOTTOM  14 14 15 1 1 1 0 L ,XT
BOTTOM  15 15 16 1 1 1 0 L ,XT
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .25 .5 .25
1 .25 .5 .25
```

```
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
1 .25 .5  .25
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
AUTOJOIN   2  1
AUTOJOIN   3  2
END
SUBSTRUCTURE  6  0  0
0.  0.  0.
MODULE 1  -1260.  0.  0.
18  0  ,  0  0  1  0  1  Y  N  1
12  ,  ,  1.0  0  1.0
-274.511  265.428  -232.851  279.194
-274.511  262.866  -232.478  249.556
-275.886  260.986  -249.627  225.324
-278.18  260.161  -278.146  216.191
-280.539  261.021  -306.665  225.324
-281.914  262.93  -324  249.183
-281.504  265.287  -324  279
-280.504  267.297  -306.106  302.853
-278.18  268.037  -278.519  312
-275.886  267.332  -250.377  303.239
END
BOTTOM  1  1  2  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  2  2  3  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  3  3  4  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  4  4  5  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  5  5  6  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  6  6  7  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  7  7  8  2  2  2  0  LCY H8 -XT H96 -1
BOTTOM  8  8  9  2  2  2  0  LCY H8  -XT  H96 -1
BOTTOM  9  9  10  2  2  2  0  LCY H8 -XT  H96 -1
BOTTOM 10  10  1  2  2  2  0  LCY H8 -XT  H96  -1
END
END
SUPER  1  "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM  1  2  3  10  1   2  .25
```

```
+    2 3 4 9  10 2 .25
+    3 4 5 8  9  2 .25
+    4 5 6 7  8  2 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2   -1044 0.  0.
10 0 ,  0 0 1 0 1 N N 1
12. , ,  1.0  0  1.0
-232.851  279.194
-232.478  249.556
-249.627  225.324
-278.146  216.191
-306.665  225.324
-324      249.183
-324      279.007
-306.106  302.853
-278.519  312
-250.377  303.239
END
BOTTOM  1  1  2  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  2  2  3  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  3  3  4  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  4  4  5  2  2  2  0  LCY H96 -XT H96 -1
BOTTOM  5  5  6  2  2  2  0  LCY H96 -XT H96 -1
```

```
BOTTOM 6 6 7 2 2 2 0 LCY H96 -XT H96 -1
BOTTOM 7 7 8 2 2 2 0 LCY H96 -XT H96 -1
BOTTOM 8 8 9 2 2 2 0 LCY H96 -XT H96 -1
BOTTOM 9 9 10 2 2 2 0 LCY H96 -XT H96 -1
BOTTOM 10 10 1 2 2 2 0 LCY H96 -XT H96 -1
END
END
SUPER 1 "TRANSVERSE BULKHEAD"
SECTION 2.8
END
ELEM 1 2 3 10 1 2 .25
+   2 3 4 9 10 2 .25
+   3 4 5 8 9 2 .25
+   4 5 6 7 8 2 .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - MODIFICATIONS TO THE STRUCTURAL MODEL
PANEL 1 10 THRU 0
FRAME 1 10 THRU 0
END
MODULE 3 -924 0. 0.
6 0 , 0 0 1 0 1 N N 1
12. , , 1.0 0 1.0
-232.851 279.194 -253.924 271.984
-232.478 249.556 -253.924 255.405
-249.627 225.324 -262.503 243.149
```

```
-278.146  216.191  -278.028  238.655
-306.665  225.324  -293.143  242.74
-324      249.183  -303.357  256.222
-324      279      -303.357  272.155
-306.106  302.853  -294.369  284.003
-278.519  312      -278.028  290.539
-250.377  303.239  -262.503  285.178
END
BOTTOM  1  1  2  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  2  2  3  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  3  3  4  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  4  4  5  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  5  5  6  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  6  6  7  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  7  7  8  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  8  8  9  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM  9  9  10  2  2  2  0  LCY H96 -XT H52 -1
BOTTOM 10  10  1  2  2  2  0  LCY H96 -XT H52  -1
END
END
SUPER  1  "TRANSVERSE BULKHEAD"
SECTION 0
END
ELEM  1  2  3  10  1   2  .25
+    2  3  4  9   10  2  .25
+    3  4  5  8   9   2  .25
+    4  5  6  7   8   2  .25
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
0  0  .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
1  .6  .4  .4
```

```
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 4 -852 0. 0.
1 0 , 0 0 1 0 1 N N 1
12. , , 1.0 0 1.0
-253.924 271.984 -274.511 265.428
-253.924 255.405 -274.511 262.866
-262.503 243.149 -275.886 260.986
-278.028 238.655 -278.18 260.161
-293.143 242.74 -280.539 261.021
-303.357 256.222 -281.914 262.93
-303.357 272.155 -281.504 265.287
-294.369 284 -280.504 267.297
-278.028 290.539 -278.18 268.037
-262.503 285.178 -275.886 267.332
END
BOTTOM 1 1 2 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 2 2 3 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 3 3 4 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 4 4 5 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 5 5 6 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 6 6 7 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 7 7 8 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 8 8 9 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 9 9 10 2 2 2 0 LCY H52 -XT H8 -1
BOTTOM 10 10 1 2 2 2 0 LCY H52 -XT H8 -1
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
```

```
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
1 .6 .4 .4
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
AUTOJOIN   2 1
AUTOJOIN   3 2
AUTOJOIN   4 3
END
SUBSTRUCTURE 7
0. 0. 0.
MODULE 1 -924. 0. 0.
6 0 , 0 0 1 0 1 Y Y 1
12 , , 1.0 0 1.0
-144     312
-170     288     -170     265
-182     288     -182     265
-194     288     -194     265
-206     288     -206     265
-218     288     -218     265
-232.9   288     -232.9   265
-250.377 303.239 -248     267
-249.627 225.324 -248     261
-232.9   240     -232.9   263
-218     240     -218     263
-206     240     -206     263
-194     240     -194     263
-182     240     -182     263
-170     240     -170     263
-144     204
END
BOTTOM   1 1 2 1 1 1 0 L , XT
BOTTOM   2 2 3 1 1 1 0 L , XT
BOTTOM   3 3 4 1 1 1 0 L ,XT
BOTTOM   4 4 5 1 1 1 0 L ,XT
BOTTOM   5 5 6 1 1 1 0 L ,XT
BOTTOM   6 6 7 1 1 1 0 L ,XT
BOTTOM   7 7 8 1 1 1 0 L ,XT
BOTTOM   8 8 9 1 1 1 0 T ,XT
BOTTOM   9 9 10 1 1 1 0 L,XT
BOTTOM   10 10 11 1 1 1 0 L,XT
BOTTOM   11 11 12 1 1 1 0 L,XT
BOTTOM   12 12 13 1 1 1 0 L,XT
BOTTOM   13 13 14 1 1 1 0 L,XT
BOTTOM   14 14 15 1 1 1 0 L,XT
BOTTOM   15 15 16 1 1 1 0 L,XT
END
END
ENDSUP
```

```
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
MODULE 2 -1044. 0. 0.
10 0 , 0 0 1 0 1 Y Y 1
12 , , 1.0 0 1.0
-144     312
-170     288
-182     288
-194     288
-206     288
-218     288
-232.9   288
-250.377 303.239
-249.627 225.324
-232.9   240
-218     240
```

```
-206    240
-194    240
-182    240
-170    240
-144    204
END
BOTTOM   1 1 2 1 1 1 0 L , XT
BOTTOM   2 2 3 1 1 1 0 L , XT
BOTTOM   3 3 4 1 1 1 0 L , XT
BOTTOM   4 4 5 1 1 1 0 L , XT
BOTTOM   5 5 6 1 1 1 0 L , XT
BOTTOM   6 6 7 1 1 1 0 L , XT
BOTTOM   7 7 8 1 1 1 0 L , XT
BOTTOM   8 8 9 1 1 1 0 T , XT
BOTTOM   9 9 10 1 1 1 0 L , XT
BOTTOM   10 10 11 1 1 1 0 L , XT
BOTTOM   11 11 12 1 1 1 0 L , XT
BOTTOM   12 12 13 1 1 1 0 L , XT
BOTTOM   13 13 14 1 1 1 0 L , XT
BOTTOM   14 14 15 1 1 1 0 L , XT
BOTTOM   15 15 16 1 1 1 0 L , XT
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
1 1 .87 3 .87 3 .87
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
3 .87 3 .87
```

```
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
3 .87 3  .87
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - MODIFICATIONS TO THE STRUCTURAL MODEL
PANEL  4  10  THRU  0
FRAME  4  10  THRU  0
END
MODULE 3  -1140.  0.  0.
8 0 , 0 0 1 0 1 Y N 1
12 , , 1.0 0 1.0
-144     312
-170     265     -170      288
-182     265     -182      288
-194     265     -194      288
-206     265     -206      288
-218     265     -218      288
-232.9   265     -232.9    288
-250     265     -250.377  303.239
-250     263     -248.627  225.324
-232.9   263     -232.9    240
-218     263     -218      240
-206     263     -206      240
-194     263     -194      240
-182     263     -182      240
-170     263     -170      240
-144     216
END
BOTTOM   1 1 2 1 1 1 0 L , XT
BOTTOM   2 2 3 1 1 1 0 L , XT
BOTTOM   3 3 4 1 1 1 0 L , XT
BOTTOM   4 4 5 1 1 1 0 L , XT
BOTTOM   5 5 6 1 1 1 0 L , XT
BOTTOM   6 6 7 1 1 1 0 L , XT
BOTTOM   7 7 8 1 1 1 0 L , XT
BOTTOM   8 8 9 1 1 1 0 T , XT
BOTTOM   9 9 10 1 1 1 0 L , XT
BOTTOM   10 10 11 1 1 1 0 L , XT
BOTTOM   11 11 12 1 1 1 0 L , XT
BOTTOM   12 12 13 1 1 1 0 L , XT
BOTTOM   13 13 14 1 1 1 0 L , XT
BOTTOM   14 14 15 1 1 1 0 L , XT
BOTTOM   15 15 16 1 1 1 0 L , XT
END
END
ENDSUP
!GROUP VIII
$GROUP IX - PANEL SCANTLINGS
```

```
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
0 0 .25
$GROUP X - GIRDER SCANTLINGS
$GROUP XI - FRAME SCANTLINGS
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
1 .25 .5 .25
$GROUP XII(a) - ADDL. PANEL SCANTLINGS
END
$GROUP XV - DELETIONS
END
AUTOJOIN   2 1
AUTOJOIN   3 2
END
$GROUP XVII
BETWEEN 1 2
AUTOJOIN 6 1
BETWEEN 3 5
AUTOJOIN 2 1
JOIN 2 2 1 3 16 3
+    2 3 1 3 1  3
+    2 2 2 3 16 6
+    2 3 2 3 1  6
AUTOJOIN 2 3
AUTOJOIN 2 2
BETWEEN 1 3
AUTOJOIN 2 1
```

```
AUTOJOIN 2  2
AUTOJOIN 3  2
AUTOJOIN 4  2
JOIN  5 5 0 2 4 1
AUTOJOIN 5  2
JOIN  6 5 3 2 4 1
AUTOJOIN 6  2
BETWEEN 4 5
AUTOJOIN 1 2
AUTOJOIN 1 3
AUTOJOIN 3 1
AUTOJOIN 3 2
AUTOJOIN 4 1
AUTOJOIN 4 2
AUTOJOIN 4 3
BETWEEN 6 7
AUTOJOIN 1 2
JOIN 1 1 12 3 4 2
AUTOJOIN       1 3
+           2 2
+           2 1
JOIN 3 2 4 1 5 6
AUTOJOIN  3 1
AUTOJOIN  3 2
AUTOJOIN  4 2
AUTOJOIN  4 1
BETWEEN 2 7
AUTOJOIN 2  1
+     2 2
AUTOJOIN 3 1
AUTOJOIN 3 2
END
BOUNDARY 2 4 1 1
CENTERPLANE 1 1 1 0
CENTERPLANE 1 1 3 0
CENTERPLANE 1 2 1 0
CENTERPLANE 1 2 3 0
RESTRAINT 1 1 1 1 111111
RESTRAINT 1 4 7 0 111111
RESTRAINT 1 6 1 0 111111
RESTRAINT 2 2 1 0 111111
RESTRAINT 3 1 1 2 111111
RESTRAINT 3 1 2 2 111111
RESTRAINT 3 1 3 2 111111
RESTRAINT 3 1 4 2 111111
RESTRAINT 5 2 7 0 111111
RESTRAINT 5 2 7 10 111111
+       1 2 7 3  111111
+       1 2 7 0  111111
+       1 3 9 0  111111
+       1 5 11 0  111111
+       2 1 6 0  111111
```

```
+        2 3 9 0  111111
END
LOADSET 1 "STATIC LOADS"
Y  1.0
IMMERSION  -180.

1 0 0 1
1 0 1 0
WEIGHT
1.244  1.244  1.244
1 0 0 1
1 0 1 0
WEIGHT
112


1 0 0 1
1 0 1 0
WEIGHT
133.3  133.3  133.3

1 0 0 1
1 0 1 0
WEIGHT
165.23  165.23  165.23
1 0 0 1
1 0 1 0
WEIGHT
0  165.23 0  0
1 0 0 1
1 0 1 0
WEIGHT
56  56

1 0 0 1
1 0 1 0
WEIGHT
0 0 0 0 0 0 0 0 0
0  76.9

1 0 0 1
1 0 1 0
WEIGHT
263.3  263.3  263.3  263.3  263.3  263.3  263.3  263.3
263.3  263.3  263.3  263.3  263.3  263.3  263.3



1 0 0 1
1 0 1 0
WEIGHT
```

```
76.9 76.9 76.9 76.9 76.9 76.9 76.9 76.9
76.9
1 0 0 1
1 0 1 0
WEIGHT
29.83 29.98 29.98 29.98 29.98 29.98 29.98 29.98
29.83 29.98 29.98 29.98 29.98 29.98 29.98 29.98
29.83 29.83
1 0 0 1
1 0 1 0
WEIGHT
29.83 29.83 29.83 29.83 29.83 29.83 29.83 29.83
29.83 29.83



LOADSET 2 "STARBOARD BOW"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 0. 45.
(
( 26 Blank Lines
(
(
LOADSET 3 "AFT PORT QUARTER"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 180. 235.
(
( 26 Blank Lines
(
LOADSET 4 "PORT BOW"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 180. 135.
(
( 26 Blank Lines
(
LOADSET 5 "AFT STARBOARD QUARTER"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 0. 315.
(
( 26 Blank Lines
(
LOADSET 6 "STARBOARD BEAM"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 0. 0.
(
( 26 Blank Lines
(
LOADSET 7 "PORT BEAM"
Y 1.0
IMMERSION -180. , , WAVEONLY 60. 2067.1 180. 180.
```

```
(
( 26 Blank Lines
(
LOADSET 8 "STARBOARD BOW"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  0.  45.
(
( 26 Blank Lines
(
LOADSET 9 "AFT PORT QUARTER"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  180.  235.
(
( 26 Blank Lines
(
LOADSET 10 "PORT BOW"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  180.  135.
(
( 26 Blank Lines
(
LOADSET 11 "AFT STARBOARD QUARTER"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  0.  315.
(
( 26 Blank Lines
(
LOADSET 12 "STARBOARD BEAM"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  0.  0.
(
( 26 Blank Lines
(
LOADSET 13 "PORT BEAM"
Y  1.0
IMMERSION -180. , , WAVEONLY  300.  10225.5  180.  180.
(
(  26 Blank Lines
(
END
CASE 1  "STATIC LOAD + STARBOARD BOW + PORT QUARTER SS 5"
1.0  1 2 3


CASE 2 "STATIC LOAD + STARBOARD BOW WAVE + PORT QUARTER WAVE SS 5"
1.0  1  4  5


CASE 3 "STATIC LOAD + STARBOARD BEAM + PORT BEAM SS 5"
1.0  1  6  7
```

CASE 4 "STATIC LOAD + STARBOARD BOW + PORT QUARTER SS 8"
1.0 1 8 9

CASE 5 "STATIC LOAD + STARBOARD BOW WAVE + PORT QUARTER WAVE SS 8"
1.0 1 10 11

CASE 6 "STATIC LOAD + STARBOARD BEAM + PORT BEAM SS 8"
1.0 1 12 13

ENDLOADS

APPENDIX C. DESCRIPTION AND CALCULATION OF SIMPLE STRUCTURE

This appendix provides further MAESTRO validation. A problem from TS3001, Naval Architectural class, was selected to be calculated by classical analytical means and by MAESTRO. The results for shear stress and bending moment from both MAESTRO and the analytical solution were compared.

A. DESCRIPTION OF PROBLEM

The problem description is as follows: a rectangular barge is floating empty at a draft of 3 ft. The barge is divided into five equal compartments by four weightless transverse bulkheads. The center three compartments are later filled with fresh water to 25% capacity. The barge has the following parameters:

- Length : L = 150 ft
- Beam : b = 50 ft
- Moulded Depth: h = 8 ft
- Draft : d = 3 ft.

The following are the analytical calculations for the rectangular barge:

Weight of the empty barge:
$$W = \frac{Lbd}{\rho_{sw}} \qquad (38)$$

$$W = 642.9 \text{ Lton}$$

Weight of load:
$$f = \frac{L\frac{3}{5}bh\frac{1}{4}}{\rho_{fw}} \qquad (39)$$

$$f = 250.7 \text{ Lton.}$$

Weight distribution for both the empty barge and load:

$$wd = W/L \qquad (40)$$

$$wd = 4.29 \text{ Lton/ft}$$

$$Wd = \frac{f}{90ft} \tag{41}$$

$Wd = 2.79$ Lton/ft

Buoyancy force:

$$B = W + f \tag{42}$$

$B = 893.5$ Lton

Distributive Buoyancy force:

$$bd = B / L \tag{43}$$

$bd = 5.96$ Lton/ft

The following figure illustrates the net weight, shear, and bending moment curves with the weight in the compartments.

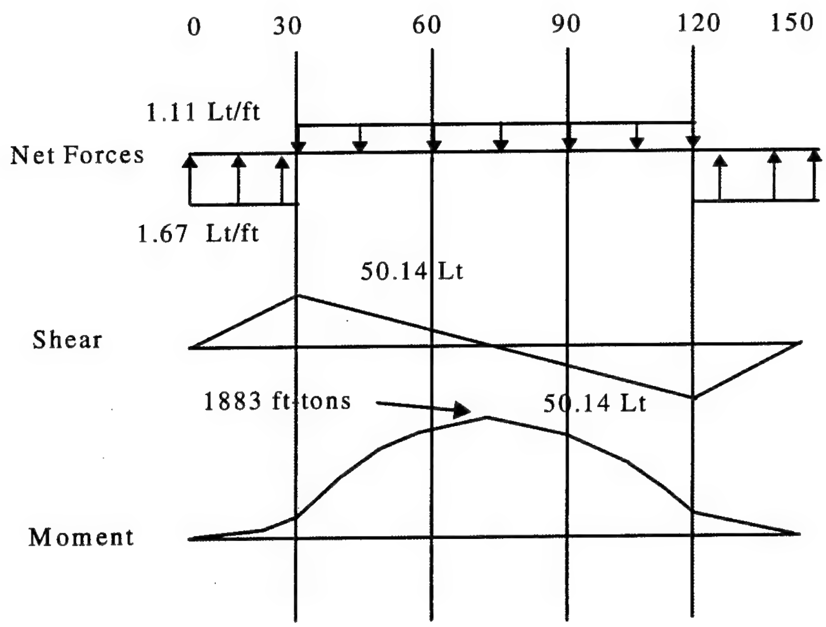

Figure 31. Weight, Shear, and Moment Curves.

The maximum shear as illustrated above is 51.14 Ltons and the maximum bending moment is 1883 ft-tons.

B. APPLICATION OF THE PROBLEM TO MAESTRO

In order to apply this problem into MAESTRO, the following assumptions are made. The first assumption is related to material selection. The material selected was 1040 steel and the appropriate Young's Modulus and yield strength were inputted into the code. The strake parameters were selected next. Since a very simple layout was selected for the structure, only three strakes were utilized. Since no details were available for the structure, the strake thickness was varied trying to match the same displacement found in the analytical solution. After finding a suitable displacement, the MAESTRO program was initiated and the following shear and bending moment results were found:

- Max shear = 55 Lton
- Max Moment = 1,923.3 ft - Ltons.

In comparing the results from both MAESTRO and the analytical solution, the difference in maximum shear is 8.8 %, and the difference in maximum bending moment is 2.23 %. The shear and bending moment differences are due to the lack of structural details. Even with the assumptions made on the structural details, the MAESTRO program is providing similar results to the analytical solutions. The MAESTRO solution would be more accurate given more structural details. This simple structure validates the MAESTRO solutions for this work.

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